Original Paper DOI: 10.5604/965479 Biol. Sport 2011;28:239-243

APPLICATION OF ALLOMETRY FOR DETERMINATION OF STRENGTH PROFILE IN YOUNG FEMALE ATHLETES FROM DIFFERENT SPORTS

Accepted for publication 02.11.2011

AUTHORS: Gajewski J.[1,2], Buśko K.[2,3], Mazur J.[2], Michalski R.[2]

[1] Department of Statistics, Józef Piłsudski University of Physical Education in Warsaw, Poland
[2] Department of Biomechanics, Institute of Sport, Warsaw, Poland
[3] Department of Anthropology, Józef Piłsudski, University of Physical Education in Warsaw, Poland

Reprint request to:
Jan Gajewski
Institute of Sport
Str. Trylogii 2/16
01-982 Warsaw, Poland
E-mail: jan.gajewski@awf.edu.pl

ABSTRACT: The goal of the study was to determine a strength profile in young female athletes practising different sports and to use allometry to evaluate muscular strength with respect to body mass. The study included 42 women who practised taekwondo (n = 10), weightlifting (n = 10), canoeing (n = 14) and speed skating (n = 8). Measurements of maximal muscle torques under static conditions in 10 groups of flexors and extensors of the elbow, shoulder, hip, knee and trunk were carried out. The MANCOVA procedure was employed to compare means between the groups. A logarithm of body mass was adopted as a covariate. Relationships between body mass and muscle torques in each muscle group were determined using a procedure of linear regression. The analysis of residuals was employed for the evaluation of maximal muscle torques. Mean values of logarithms of maximal muscle torques were significantly different for the representatives of individual sports and they depended on the logarithm of body mass. It was proposed to use a mean of residuals normalized for individual muscle groups as a synthetic strength index (mean of the strength profile). The women practising canoeing were characterized by the highest strength index. Its lowest values were obtained by weightlifting and taekwondo athletes. Differences in strength profiles in the tested athletes were attributed to the specific nature of their sports. It is suggested to use an allometric relationship scaled by body mass for strength assessment.

KEY WORDS: allometry, muscle torques, women, taekwondo, weightlifting, canoeing, speed skating

INTRODUCTION

Allometry is the study of the relationships between selected values which characterize a particular system. These relationships are also termed a power law or scaling law. Allometric scaling considers differences in build which result from sizes and describes these differences in mathematical terms as power functions [24]:

$$y = a\,x^b \qquad (1)$$

After logarithmic transformation of both sides of the equation, it adopts the form of a straight line equation, with the independent variable being log*x*, whereas the dependent variable is log*y*:

$$\log y = b \log x + \log a \qquad (2)$$

In both equations, *x* is the value which defines the size, whereas *y* is the measured characteristic, e.g. the value of developed force or a result obtained during a weightlifting competition [1]. This type of dependency on body mass or height reflects an optimal adaptation to the conditions of the environment and is met by a number of biological variables. There are a number of studies available in the literature which have described allometric dependency on body mass and/or body height and grip force [14,21], strength and torques in flexors, extensors and rotators in the hip joint [2], maximal force measured by the result of 1 repetition maximal (1RM) [1,15,16], maximal oxygen uptake [13,17,18,22], and rowing speed measured with a rowing ergometer at a distance of 2000 m [13]. There are also a number of studies in the available literature which have demonstrated the relationships between maximal muscle torques in individual human muscle groups [3,6,11,19,20]. However, they have not been calculated using the allometric method yet, and the synthetic assessment of the force understood as a motor characteristic, based on the sum of maximal muscle torques, does not seem to be sufficiently justified.

The aim of the present study was to determine the strength profile which typifies young female athletes from different sports and to use the method of allometry for a synthetic evaluation of strength with respect to body mass.

MATERIALS AND METHODS

The study was approved by the Ethics Committee of the Institute of Sport in Warsaw, Poland. All participants were informed about the study aim and methodology as well as about the possibility of

TABLE 1. SOMATIC CHARACTERISTICS OF THE STUDIED GROUPS

Sport	Number of Subjects	Age [years]	Body Mass [kg]	Body Height [cm]	Experience [years]
Taekwondo	10	15.7 ± 1.0	53.3 ± 8.3	164.5 ± 6.4	5.56 ± 3.50
Weightlifting	10	15.4 ± 1.2	63.5 ± 17.9	162.0 ± 10.4	2.48 ± 1.38
Canoeing	14	16.7 ± 1.2	64.9 ± 6.6	169.4 ± 5.5	4.43 ± 1.59
Speed Skating	8	17.6 ± 1.6	62.5 ± 3.3	166.0 ± 2.2	6.38 ± 2.50

immediate withdrawal from the study at any time. Subjects agreed on the above conditions in writing. The study included 42 women who practise taekwondo, weightlifting, canoeing and speed skating. The characteristics of the subjects included in the study are presented in Table 1.

Measurements of maximal muscle torques in ten muscle groups (flexors and extensors of the elbow, shoulder, hip, knee and trunk) were taken in a testing station for measurements of muscle torques under static conditions [5]. The muscle torques in elbow flexors and extensors were measured in a sitting position. The subject's arm was supported on an armrest. The angle at the arm joint was 90°. The forearm was positioned at a right angle with respect to the arm. The measurements of muscle torque of arm flexors and extensors were taken in a sitting position. The angle of the arm joint during extension was 70°, with this value being 50° during flexion. The body trunk was in contact with the testing station and was stabilized by the chest pressed against the testing station by an assistant. The muscle torques in knee flexors and extensors and trunk flexors and extensors were measured in a sitting position. The angle at the hip and knee joints was 90°. The subjects were stabilized at the level of the anterior iliac spine and in the further part of the thigh. Upper limbs were crossed on the subject's chest. Muscles which extended the limb at the hip joint were measured in face-up position. The angle at the hip joint was 90°. The subject stabilized the trunk, holding the testing station with the hands. Maximal extension of a limb at the elbow, knee and hip joint was adopted as 0°. At the arm joint, position of the limb along the trunk was adopted as 0°. Position of the trunk in face-up position was adopted as 0°. Rotation axis at the measured joint covered with the rotation axis of the torque meter. Both upper and lower limbs were measured, separately for the left and right side, maintaining the order of flexion-extension. The subjects were instructed to develop maximal value of muscle torque.

Muscle torques were also presented as a percentage of individual muscle groups, calculated in relation to their sum (topography of muscle strength) [6,20].

The analysis used mean values obtained for the left and right limb. All the measurements were performed in the morning.

Statistical analysis of the results of the study was supported with STATISTICA™ software (v. 9.0, StatSoft, USA). The data were subjected to a logarithmic transformation. The Shapiro-Wilk test was used in order to evaluate the normality of distribution. A criterion $p>0.05$ was adopted as not excluding normality. The multivariate analysis of covariance (MANCOVA) was employed in order to analyse mean values between the groups. The logarithm of body mass was used as a covariate. The differences between the mean values for individual sports were analysed by means of Tukey's post-hoc analysis for unequal sample sizes. In order to determine the relationship between body mass and muscle torque in each muscle group, the authors used a procedure of linear regression. The linear regression analysis was based on the allometric relationship scaled with body mass, with the regression equation presented in a logarithmic form, and the allometric relationship expressed by equations (3) and (4), respectively:

$$\ln M_{oi}(m) = a_i \ln m + b_i, \quad (3)$$

$$M_{oi}(m) = B_i m^{a_i}, \quad (4)$$

where:

M_{oi} = expected torque for *i* muscle group,

m = body mass,

a_i and b_i are regression coefficients for *i* muscle group,

$B_i = e^{b_i}$.

The analysis of residuals was used in order to evaluate the maximal muscle torques. A residual is the difference between the actual and expected torques:

$$d = \ln M_{observed} - \ln M_{expected} \quad (5)$$

where:

d = residual,

M = torque.

In order to present the place of subject *j* in the group, normalized residuals were used (d_j^*), i.e. residuals divided by standard error of regression (6):

$$d_j^* = \frac{\ln M_j - \ln M_o}{SE} = \frac{d_j}{SE} \quad (6)$$

where:

d_j = residual,

SE = standard regression error, $SE = \sqrt{\frac{\sum_{j=1}^{n} d_j^2}{n-2}}$

n = number of subjects.

RESULTS

Mean values (SD) of maximal muscle torques generated by female athletes who practise taekwondo, weightlifting, canoeing and speed skating are presented in Table 2. Before further analysis was carried out, it was demonstrated that the distributions of logarithms of maximal muscle torques can be assumed as normal (Shapiro-Wilk test, $p>0.05$).

TABLE 2. MEAN VALUES (±SD) OF MAXIMAL MUSCLE TORQUES (Mi) IN FLEXORS (F) AND EXTENSORS (E) IN BOTH LIMBS, IN ELBOW, ARM, HIP AND KNEE JOINTS AND IN TRUNK FLEXORS AND EXTENSORS IN FEMALE ATHLETES (N=42) WHO PRACTICE TAEKWONDO, WEIGHTLIFTING, CANOEING AND SPEED SKATING

Muscle Group		Mi [N·m] Taekwondo n=10	Mi [N·m] Weightlifting n=10	Mi [N·m] Canoeing n=14	Mi [N·m] Speed Skating n=8
Elbow Joint	F	34.4 ± 6.7	43.7 ± 10.3 [a]	49.9 ± 6.5 [ab]	36.4 ± 5.5 [bc]
	E	22.0 ± 4.7	28.3 ± 7.7 [a]	30.9 ± 4.4 [a]	25.9 ± 3.4 [ac]
Arm Joint	F	30.4 ± 8.3	41.0 ± 9.9 [a]	39.6 ± 7.3 [a]	38.1 ± 5.0 [a]
	E	33.4 ± 8.9	40.0 ± 11.4 [a]	51.9 ± 7.7 [ab]	42.0 ± 7.4 [ac]
Knee Joint	F	80.0 ± 14.7	82.8 ± 23.8	91.4 ± 16.3 [a]	82.0 ± 13.3
	E	159.0 ± 37.1	221.5 ± 82.6 [a]	184.8 ± 40.9 [b]	226.7 ± 49.1 [ac]
Hip Joint	F	66.5 ± 15.0	64.2 ± 20.4	75.2 ± 11.6 [b]	78.5 ± 12.0 [ab]
	E	265.1 ± 82.8	328.2 ± 160.1	312.8 ± 85.4	340.1 ± 3.2
Trunk	F	104.8 ± 27.2	110.5 ± 37.7	145.7 ± 30.3 [ab]	141.1 ± 13.3 [ab]
	E	290.7 ± 70.1	319.2 ± 103.2	375.4 ± 69.0 [ab]	361.6 ± 62.4 [a]

a - mean values which differ significantly compared to taekwondo, $p<0.05$;
b - mean values which differ significantly compared to weightlifting, $p<0.05$;
c - mean values which differ significantly compared to canoeing, $p<0.05$.

TABLE 3. LINEAR REGRESSION COEFFICIENTS WHICH DESCRIBE THE DEPENDENCY (3) OF LOGARITHMS OF MAXIMAL MUSCLE TORQUES IN INDIVIDUAL MUSCLE GROUPS ON THE LOGARITHM OF BODY MASS FOR THE GROUP OF FEMALE ATHLETES (N=42)

Coefficient	Elbow flex.	elbow ext.	Arm flex.	Arm ext.	Knee flex.	Knee ext.	Hip flex.	Hip ext.	Trunk flex.	Trunk ext.
ai	0.957	0.851	0.917	1.123	0.576	1.072	0.891	1.283	1.370	1.163
bi	-0.208	-0.212	-0.167	-0.884	2.057	0.838	0.589	0.401	-0.815	1.028

Mean logarithms of maximal muscle torques were compared for the representatives of different sports. In multivariate analysis of covariance (MANCOVA), the analysed factor was the type of sport and the covariate was body mass logarithm. It was demonstrated that mean logarithms of muscle torques are significantly different for the representatives of individual sports ($F_{30,83} = 3.80$; $p<0.001$) and depend on body mass logarithm ($F_{10,28} = 18.30$; $p<0.001$). The results of detailed post-hoc comparison are presented in Table 2. Comparisons were made for weighted means with respect to the dependency of the studied variables on body mass logarithm.

The results from linear regression analysis carried out for the whole study group are presented in Table 3. The values of normalized residuals were calculated for each subject and each studied muscle group. The vector of residuals obtained in this way was termed strength profile in the study.

Figure 1 presents an example plot with the regression line for the dependency of log maximal muscle torque (flexion at elbow joint) on log body mass.

Figure 2 presents strength profiles for female athletes who practise different sports.

Similar profiles were observed in the subjects who trained in speed skating and taekwondo (higher values for lower limbs and trunk), whereas the female athletes who practise canoeing obtained higher values for upper limbs and trunk. Relatively poor results were obtained by female weightlifters.

For the purposes of this study, strength index is defined as an arithmetic mean of strength profile components. Figure 3 presents the strength index for the tested women.

Women who trained in canoeing were characterized by the highest strength index. The lowest strength index was obtained by the female athletes who trained in weightlifting and taekwondo.

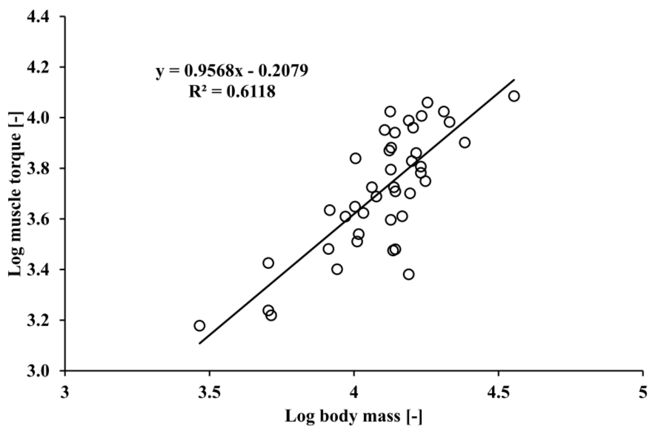

FIG. 1. RELATIONSHIP BETWEEN THE LOGARITHM OF MAXIMAL MUSCLE TORQUE IN ELBOW FLEXORS AND THE LOGARITHM OF BODY MASS (N=42)

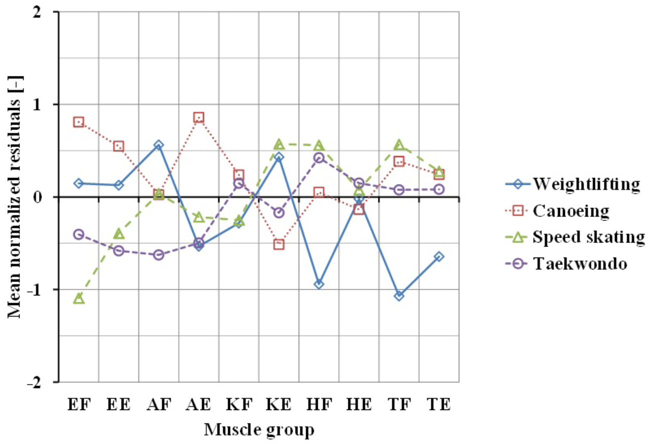

FIG. 2. MEAN STRENGTH PROFILES FOR FEMALE ATHLETES FROM DIFFERENT SPORTS (EF – ELBOW JOINT, FLEXION, EE – ELBOW JOINT, EXTENSION, AF – ARM JOINT, FLEXION, AE – ARM JOINT, EXTENSION, KF – KNEE JOINT, FLEXION, KE – KNEE JOINT, EXTENSION, HF – HIP JOINT, FLEXION, HE – HIP JOINT, EXTENSION, TF – TRUNK, FLEXION, TE – TRUNK, EXTENSION)

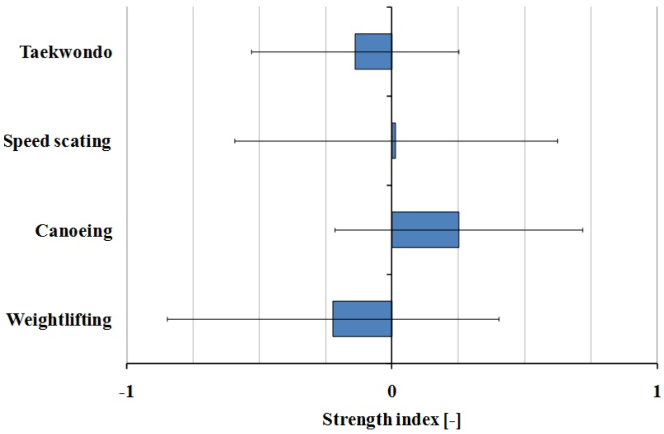

FIG. 3. MEAN VALUES OF STRENGTH INDEX (±SD) (CALCULATED FOR INDIVIDUAL SUBJECTS AS MEAN VALUES OF STRENGTH PROFILE) FOR THE REPRESENTATIVES OF DIFFERENT SPORTS (N=42)

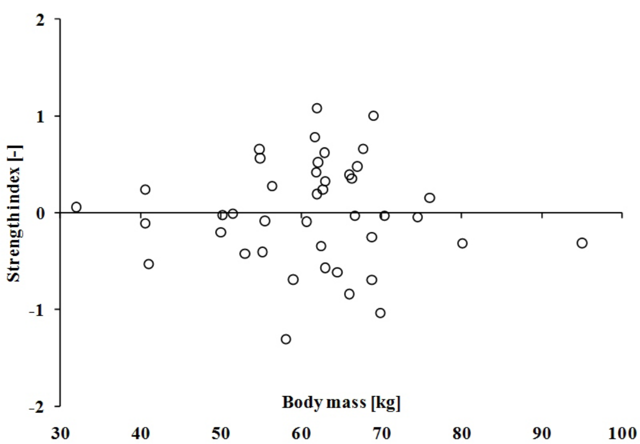

FIG. 4. MEAN RESIDUALS NORMALIZED FROM REGRESSION OF LOGARITHMS OF MAXIMAL MUSCLE TORQUES TO BODY MASS LOGARITHMS (STRENGTH INDICES) VS BODY MASS FOR ALL THE FEMALE ATHLETES INCLUDED IN THE STUDY (N=42)

Figure 4 presents the values of strength index for all the subjects vs. body mass. The residuals are located properly and no dependency of their value on body mass is observed.

DISCUSSION

Measurement of maximal muscle torques under static conditions is a routine method used for determination of muscle force in laboratory testing [4,5,6,7,8,19]. The analysis predominantly involves the values of force generated by the muscles of the upper and lower limb, one body side (upper limb, lower limb and trunk) or both sides. Assessment of muscle force is frequently made by means of the absolute sum and/or relative sum of muscle torques in the main muscle groups [6,11,23]. Mutual relations of maximal muscle forces in individual human muscle groups are defined as a strength profile [3], topography of muscle strength [19] or topography of muscle torques [6]. The factors which 'disturb' proper interpretation might include different contribution of maximal muscle torques in individual muscle groups to their algebraic sum which results from the specific character of a sport and/or calculation of relative values (calculation per body mass kilogram) in the sports with weight categories.

A relationship between body size of weightlifters and the obtained results has been discussed in a number of studies [1,15,16]. The authors considered linear as well as curvilinear relationships. In 1985, Sinclair [15] proposed the use of the method of allometric scaling for comparison of the results obtained by weightlifters from different weight categories. The relationship was described by the second-degree polynomial. Stone et al. [16] used the scaling method to search for relationships between maximal force measured with 1RM squat performance and the results from the snatch test in female and male weightlifters. The observations were obtained using Pearson's correlation coefficients, allometric method and Sinclair's method [15]. A significant relationship was found between the result from 1RM squat performance and the results of snatch tests, at the level of 0.84, independently of body mass and height. Furthermore, the strength estimates were still higher for men than women, even if body mass and height were eliminated using the scaling methods. Batterham and George [1] used the allometric model to search for relationships between body mass (weight categories) and the results from weightlifting competitions taking into consideration gender. They demonstrated that the allometric model 'punishes' lighter and heavier competitors. Similar results were obtained by Sinclair [15]. According to Batterham and George [1], a linear model is not always appropriate for the analysis of biological relationships. Sometimes, it is more appropriate to use a polynomial or a logarithmic scale. It is generally accepted that a negative impact of high body mass depends on lean body mass. Forbes [10] estimated that the upper limit for lean body mass is 100 kg for men and 60 kg for women. These values correspond to body mass of ca. 110-120 kg in men and 70-80 kg in women. Increase in body mass over these values might be caused by an increase in the content of fat tissue.

In our study, body mass in two athletes (32 and 90 kg) can be found as extremely low and extremely high. However, the effects described by Batterham and George [1] were not found (Figure 5). In summary, however, one should bear in mind that even if it is possible to find a straight line which matches the data and to determine the correlation coefficient, standard deviation and confidence interval, it still remains merely a mathematical description of numerical data, and its statistical significance does not guarantee biological significance.

CONCLUSIONS

1. Similar strength profiles were found in female speed skaters and taekwondo contestants, which might result from the specific character of both sports.
2. The authors propose the use of an allometric relationship which takes body mass into consideration during evaluation of strength in individual muscle groups, because the values of muscle torques are not in direct proportion to body mass and their mutual proportions change with an increase in body mass.
3. The mean value of residuals normalized for individual muscle groups (the mean from the strength profile) is recommended to be used as a synthetic strength index.

Acknowledgement
This study was supported by the AWF grant DS-140.

REFERENCES

1. Batterham A., George K. Allometric modeling does not determine a dimensionless power function ratio for maximal muscualr function. J Appl. Physiol. 1997;83:2158-2166.
2. Bazzet-Jones D., Cobb S., Joshi Mukta N., Cashin S., Earl J. Normalizing hip muscle strength: establishing body-size-independent measurements. Arch. Phys. Med. Rehabil. 2011;92:76-82.
3. Bober T., Pietraszewski B. Strength of muscle groups in swimmers. Biol. Sport 1996;13:155-164.
4. Boguszewska K., Boguszewski D., Buśko K. Special judo fitness test and biomechanics measurements as a way to control of physical fitness in young judoists. Arch.f Budo 2010;6:OA205-209. Manuscript ID: 881273.
5. Buśko K., Gajewski J. Muscle strength and power of elite female and male swimmers. Bal. J. Health and Phys. Activ. 2011;3:13-18.
6. Buśko K, Nowak A. Changes of maximal muscle torque and maximal power output of lower extremities in male judoists during training. Hum. Mov. 2008;9:111–115.
7. Buśko K., Madej A., Mastalerz A. Changes of muscle torque after sprint and endurance training performed on the cycle ergometer. Biol. Sport 2008;25:275-294.
8. Buśko K., Rychlik R.: Changes of the maximal muscle torque in women training Power Yoga (Astanga Vinyasa). Hum. Mov. 2006;7:168-177.
9. Drid P., Drapsin M., Trivic T., Lukač D., Obadov S., Milosevic Z. Asymmetry of muscle strength in elite athletes. Biomed. Hum. Kinetics 2009;1:3-5.
10. Forbes G. B. Human Body Composition: Growth, Aging, Nutrition and Activity. Springer-Verl., New York 1987.
11. Janiak J., Wit A., Stupnicki R.Static muscle force in athletes practising rowing. Biol Sport 1993;10:29-34.
12. Kabitsis C., Nevill A. M. Power output during arm cycling and its relationship to body size and throwing performance. J. Sports Sci. 1992;10:568–569.
13. Nevill A.M., Allen S.V., Ingham S.A. Modelling the determinants of 2000 m rowing ergometer performance: a proportional, curvilinear allometric approach. Scand. J. Med. Sci. Sports 2011;21:73-8. doi: 10.1111/j.1600-0838.2009.01025.x.
14. Pua Y-H. Allometric analysis of physical performance measures in older adults. Phys. Ther. 2006;86:1263-1270.
15. Sinclair R.G. Normalizing the performances of athletes in Olympic Style weightlifting. Can. J. Appl. Sport Sci. 1985;10:94–98.
16. Stone M.H., Sands W.A., Pierce K.C., Carlock J., Cardinale M., Newton R.U. Relationship of maximum strength to weightlifting performance. Med. Sci. Sports Exerc. 2005;37:1037-1043.
17. Tartaruga M.P., de Medeiros M.H., Alberton C.L., Cadore E.L., Peyré-Tartaruga L.A., Baptista R.R., Coertjens M., Kruel L.F.M. Application of the allometric scale for the submaximal oxygen uptake in runners and rowers. Biol Sport 2010;27:297-300.
18. Tartaruga M.P., Peyré-Tartaruga L.A., Coertjens M., De Medeiros M.H., Kruel L.F.M. The influence of the allometric scale on the relationship between running economy and biomechanical variables in distance runners Biol. Sport 2009; 26:263-273.
19. Trzaskoma Z, Trzaskoma Ł. The proportion between maximal torque of core muscles in male and female athletes. Acta Bioeng. Biomech. 2001;3(Suppl. 2):601-606.
20. Trzaskoma Z, Trzaskoma Ł. Structure of maximal muscle strength of lower extremities in highly experienced athletes. Phys. Educ. Sport 2006;50:73-78.
21. Vanderburgh P. M., Mahar M. T., Chou C. H. Allometric scaling of grip strength by body mass in college-age men and women. Res. Q. Exerc. Sport 1995;66:80–84.
22. Vanderburgh P.M., Katch F.I. Ratio scaling of VO_2max penalizes women with larger percent body fat, not lean body mass. Med. Sci. Sports Exerc. 1996;28:1204-1208.
23. Wit A., Eliasz J., Gajewski J., Janiak J., Jaszczuk J., Trzaskoma Z. Maximal isometric muscle torque assessment in elite athletes. Acta Bioeng. Biomech. 2002;4(Suppl. 1):591-592.
24. West G.B., Brown J.H. The origin of allometric scaling laws in biology from genomes to ecosystems towards a quantitative unifying theory of biological structure and organization. J. Exp. Biol. 2005;208:1575-1592.