Coll. Antropol. **30** (2006) 3: 607–613
Original scientific paper

Modeling the Influence of Body Size on Weightlifting and Powerlifting Performance

Goran Marković[1] and Damir Sekulić[2]

[1] Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia
[2] Faculty of Natural Sciences, Mathematics and Education, University of Split, Split, Croatia

A B S T R A C T

The purpose of this study was to examine 1) if lifting performance in both the weightlifting (WL) and powerlifting (PL) scale with body mass (M) in line with theory of geometric similarity, and 2) whether there are any gender differences in the allometric relationship between lifting performance and body size. This was performed by analyzing ten best WL and PL total results for each weight class, except for super heavyweight, achieved during 2000–2003. Data were analysed with the allometric and second-order polynomial model, and detailed regression diagnostics was applied in order to examine appropriateness of the models used. Results of the data analyses indicate that 1) women's WL and men's PL scale for M in line with theory of geometric similarity, 2) both WL and PL mass exponents are gender-specific, probably due to gender differences in body composition, 3) WL and PL results scale differently for M possibly due to their structural and functional differences. However, the obtained mass exponents does not provide size-independent indices of lifting performances since the allometric model exhibit a favourable bias toward middleweight lifters in most lifting data analyzed. Due to possible deviations from presumption of geometric similarity among lifters, future studies on scaling lifting performance should use fat-free mass and height as indices of body size.

Key words: *allometric scaling, body size, muscle strength, polynomials, powerlifting, weightlifting*

Introduction

Muscle strength has been defined as the maximum force or torque developed during maximal voluntary contraction under a given set of conditions[1]. Although performance in almost every sport depends on certain amount of muscle strength[2], this is particularly emphasized in two sporting activities: weightlifting[3] and powerlifting. In both sports, the objective is to perform maximum lifts using different lifting techniques. Three events make up the sport of powerlifting (PL): bench press, squat, and dead lift. Weightlifting (WL) consists of two events: snatch, and clean-and-jerk. By summing the results in each lifting event, a total result can be calculated, which is usually used as a criterion of overall lifting (or strength) performance in both WL and PL.

It is well known that body size represents an important factor that affects muscle strength[1,4,5]. In particular, there exists significant positive relationship between muscle strength and body size[1]. In order to eliminate the effects of body size on lifting performance, athletes in both sports compete in different weight classes. However, in weightlifting competitions comparisons are often made among lifters who win the different weight classes so that the best lifter in the competition can be identified[6]. In order to be able to compare results of lifters from different weight classes, the results should be appropriately normalized for body mass (*M*).

The simplest method of normalizing muscle strength (or any other physiological or performance variable) is to divide the result (in this case mass lifted) with subjects' *M*, i.e. ratio standard[7–9]. However, for this ratio standard to be valid the true relationship between two variables should be linear and the regression should pass through the origin. Unfortunately, in WL and PL neither of these two conditions is satisfied, so this scaling method is inappropriate[8–11]. In particular, many studies (see Jaric[1] for review) have shown that muscle strength (and lifting performance) appears to increase at a lower rate than *M*. Therefore, ratio scaling have been shown to penalize heavier individuals because too much an adjustment would be made for *M* thus disproportionately »deflating« the overall result of heavier individuals[10,11].

Received for publication June 5, 2004

The theoretical explanation for these results is based on the presumption of geometric similarity[10], by which muscle strength should be proportional to muscle physiological cross-sectional area – which is proportional to $M^{2/3}$ – rather than M[7,13]. Therefore, other scaling models, the allometric model in particular, have been proposed and used frequently[6,7,14–16]. Allometric modelling is based on the assumption that the true relationship between depended variable (in this case, muscle strength) and an independent anthropometric variable (in this case, body mass) is curvilinear and passes through the origin (for review see Nevill and Holder[9]). Specifically, it presumes an allometric relationship:

$$S = a \cdot M^b, \qquad \text{(eq. 1)}$$

where S is muscle strength, M is body mass, b is the allometric exponent and a is constant multiplier. When allometric exponent b is determined, muscle strength (in this case mass lifted) could be expressed independent of M:

$$S_n = S / M^b, \qquad \text{(eq. 2)}$$

where S_n represents normalized muscle strength. Note that S_n corresponds to constant multiplier a (for details see Jaric[1] and Jaric et al.[4]).

This approach has been frequently applied in normalizing WL and PL performance[6,7,10,11,17–21]. However, while several studies have determined that the overall WL and PL results should scale with a theoretical mass exponent $b = 0.67$[6,11,20], some studies showed that the allometric exponent b in the WL lifting is considerably lower than 0.67, predicted by the presumption of geometric similarity[10,17]. In contrast, some researchers that modelled the total PL performance (e.g., Vanderburgh and Dooman[21]) reported mass exponent b significantly higher than 0.67.

Batterham and George[10] have also shown that body composition represents an important factor in determining the relationship between muscle strength and body mass. By excluding the subjects heavier than 91kg from their analysis, the authors obtained allometric exponent $b = 0.68$, instead of $b = 0.48$, when all weight categories were considered in analysis. It must also be noted that the majority of studies analyzed men's lifting performance[6,7,17,20] and used a rather small samples (≤ 30[6,7,10,11,17,19]). Jensen et al.[22] have elegantly shown that sample size represents an important factor in determining a true relationship between physiological variables and body size. Recently, Kauhanen et al.[8] analysed WL performance – body mass relationship on large data sets of elite WL results ($n = 1572$) and demonstrated that the overall lifting performance does not scale with theoretically predicted exponent 0.67 ($b = 0.55$; 95% confidence interval 0.53–0.56). When heaviest weight class was excluded from their analysis, mass exponent b was 0.60 (95% confidence interval 0.53–0.66), still significantly lower ($p < 0.05$) than 0.67. However, one possible confounding factor might be included in the study of Kauhanen et al.[8]. Namely, the authors included in an analysis men's lifting results from 1973 to 1999. Due to increased use of anabolic-androgenic steroids and other anabolic stimulus among strength athletes in the mid 1970s and early 1980s[23], possible increase in upper limits of lean body mass could significantly influence to the relationship between lifting performance and body mass[10].

This brief literature review suggests that different results obtained in previous studies could be the result of: a) differences in body compositions among lifters (lifters in heaviest category may be heavier because of excess body fat); and b) small sample size studied. In addition to these divergences, recent findings have indicated that second-order polynomial model provides a superior fit to elite WL and PL results than allometric model[7,10,24,25]. For this reason, Batterham and George[10] suggested that the allometric modelling should be applied only when all underlying model assumptions (i.e., regression diagnostics) have been rigorously evaluated and satisfied. Finally, there is an obvious lack of empirical data in scientific literature about the relationship between lifting performance and body size in female athletes. To further examine if lifting performance scale with the theoretically predicted exponent $b = 0.67$, and whether there are any differences in scaling lifting performance for body size between genders, we analyzed lifting performance on a relatively large sample of elite men and women weightlifters and powerlifters using both allometric and second-order polynomial model.

Materials and Methods

Performance and body size data

In this study the WL and PL data from 2000 to 2003 were analyzed. The data for WL were selected from results made in the World Championships and Olympic Games during 2000–2003 with the respective body mass measured at the official weigh-in before each competition (official web-site of the International Weightlifting Federation; www.iwf.com). The data for PL were selected form PL results made in the World Championships during 2000–2003 with the respective body mass (M) measured at the official weigh-in before each competition (official web-site of the International Powerlifting Federation; www.powerlifting-ipf.com). Although both the WL and PL consists of several lifting disciplines (see Introduction), we focused only on the total results (the sum of results in each lifting discipline) as a criterion of overall lifting performance.

Subjects

For WL, best 10 two-event total results (sum of snatch and clean-and-jerk) for each men and women weight category, except for super heavyweight (men's +105 kg and women's +75 kg), achieved during 2000–2003 were used in this study. If the same lifter had more than one result in top 10 results, only his/her best result was used in further analysis. For PL, best 10 three-event total results (sum of squat, bench press, and dead lift) achieved during 2000–2003 for men's categories up to 110 kg, and women up to 75 kg were used in this study. As for WL, if the same lifter had more than one result in top 10 results, only his/her best result was used in further analysis. The greatest weight category in WL, and categories over 110 kg for men and over 75 kg for women in PL were omitted in order to avoid possible confounding effect of body composition common in super heavyweight categories[10,11].

Data analyses

To examine if lifting performances scale with theoretically predicted mass exponent 0.67, an allometric or power function model was applied (see eq. 1). A regression technique applied on the log-transformed data provided the values of the allometric exponent b for each lifting result (see Batterham and George[10] for details of the method). In short, a log-transformation of the presumed allometric relationship (see eq. 1) between lifting performance S and body mass M gives:

$$\ln S = \ln a + b \ln M + \ln \varepsilon, \qquad \text{(eq. 3)}$$

where ln a and b, respectively, correspond to the intercept and slope of the regression line fitted through the logarithmic values of the experimentally recorded lifting results and body mass, and ε is an error term. Normality of log-transformed variables was confirmed using a Kolmogorov-Smirnov test ($p > 0.3$). Commonality of slopes of the lifting result-body mass relationships between men and women were tested by including gender and gender-by-ln M interaction term in a multiple log-linear model, as described by Batterham and George[10]:

$$\ln S = \ln a + d(G \ln M) + cG + b \ln M + \ln \varepsilon, \qquad \text{(eq. 4)}$$

A significant gender-by-ln M interaction term ($p < 0.05$) for both WL and PL results was found. Therefore, separate allometric exponents for men and women in both lifting disciplines were calculated. Allometric exponents were reported as mean ± standard error (mean ± SE), allowing construction of 95% confidence intervals (95% CI).

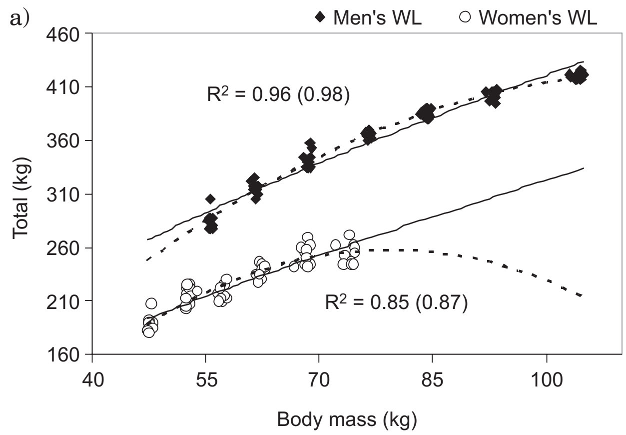
In addition, a second-order polynomial model was also applied to the same data, as recommended by Batterham and George[10]:

$$S = a + bM + cM^2, \qquad \text{(eq. 5)}$$

The differences in the lifting performance-body size relationship between allometric and second-order polynomial model were computed using two-tailed t-test for testing differences between two dependent correlation coefficients. A detailed regression diagnostics recommended by Nevill and Holder[9] and Batterham and George[10] was used to examine model fit. In brief, normality of the distribution of the residuals in both analyses was ascertained using the Kolmogorov-Smirnov test. The homoscedasticity of data (constant error variance) was tested by calculating a correlation between the raw residuals and ln M. Appropriateness of log-linear regression model was checked via detailed inspection of the scatter plot of residuals and ln M.

Results

Figure 1 depicts the scatter plots of M *vs*. lifting performances by gender in both WL (Figure 1a) and PL (Figure 1b). As expected, absolute indices of lifting performance and M suggest a strong positive relationship. The plotted relationships are curvilinear, similar to those reported by Batterham and George[10] and Vanderburgh and Batterham[11] for the WL and PL results, respectively.



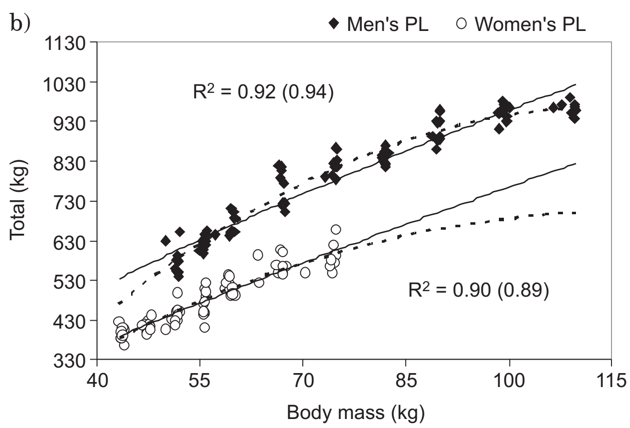


Fig. 1. Scatter plot of total lifted in weightlifting (a) and powerlifting (b) vs. body mass for men and women. Both allometic (solid line) and second-order polynomial curve (dashed line) fits are displayed together with their corresponding coefficients of determination R^2 (R^2 for second-order polynomial models in parenthesis).

The results of the allometric and the second-order polynomial model applied to the lifting performances are shown in Tables 1 and 2. The resulting solutions explained between R^2 = 85% and R^2 = 96% of the variation in lifting performances analyzed in this study. Although the second-order polynomial model explained ~ 2% more variance than allometric model for most lifting performances, this improvement was not significant ($p>0.05$).

The obtained slopes of the regression lines correspond to allometric exponents b needed to assess body mass in-

TABLE 1
ALLOMETRIC MODEL RELATIONSHIPS FOR WEIGHTLIFTING (WL) AND POWERLIFTING (PL) PERFORMANCE (S) TO BODY MASS (M)

	N	b	95% CI	Equation
Men's WL	70	0.61±0.02	0.58 – 0.64	$S=25.56M^{0.61}$
Women's WL	70	0.68±0.04	0.62 – 0.76	$S=13.85M^{0.68}$
Men's PL	90	0.69±0.02	0.65 – 0.74	$S=36.31M^{0.69}$
Women's PL	80	0.80±0.03	0.74 – 0.87	$S=19.11M^{0.80}$

N – number of subjects, 95% CI – 95% confidence interval, b – allometric parameter (X±standard error)

TABLE 2
SECOND ORDER POLYNOMIAL MODEL RELATIONSHIPS FOR WEIGHTLIFTING (WL) AND POWERLIFTING (PL) PERFORMANCE TO BODY MASS (M)

	Equation
Men's WL	$S= -0.037M^2 + 8.68M - 71.77$
Women's WL	$S= -0.068M^2 + 10.76M - 169.11$
Men's PL	$S= -0.081M^2 + 20.04M - 232.37$
Women's PL	$S= -0.070M^2 + 15.59M - 151.16$

S – normalized performance

dependent indices of lifting performance (see parameter b in eq. 3). These allometric exponents b (Table 1) represent the main result of the study. The exponents of 0.68 and 0.69 for women's WL and men's PL data are similar to the theoretical prediction of 0.67. In contrast, 95% confidence intervals of the mass exponents b for men's WL and women's PL performance do no not include the value of 0.67, suggesting that these lifting performance scale with negative and positive allometry, respectively. It must also been pointed out that women's mass exponents b were significantly higher ($p<0.05$) than men's exponents in both lifting sports (see Methods section for details).

All residual errors from fitting both models were found to be acceptably normal when using Kolmogorov Smirnov test ($p>0.4$). In addition, no linear relationship was found between residual scores and body mass for allometric modelling (correlation coefficients r ranged between –0.11 and 0.09, $p>0.05$), suggesting that the model errors displayed homoscedasticity.

The presented data suggest that both models demonstrated excellent fit to the lifting performances analyzed.

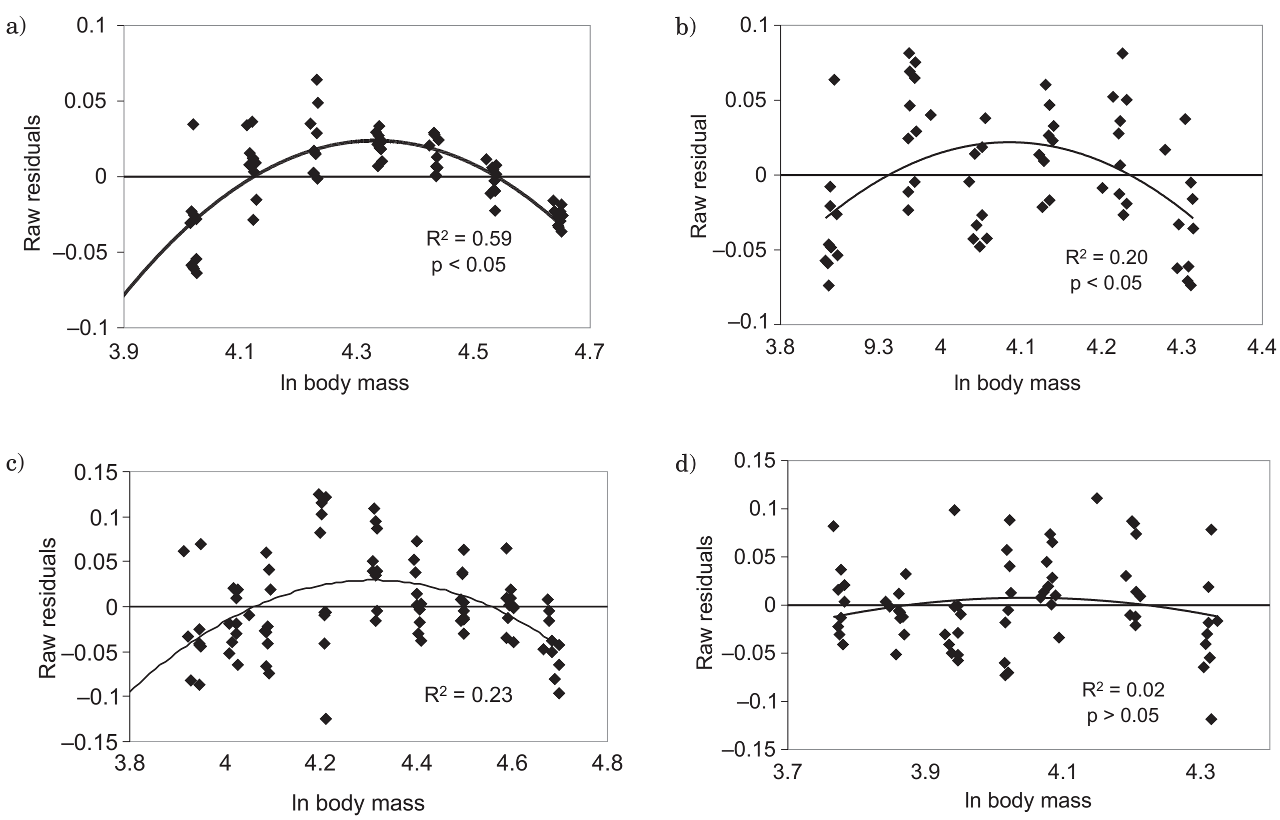


Fig. 2. Scatter plot of raw residuals vs. ln body mass for allometric model applied to: (a) men's weightlifting results, (b) women's weightlifting results, (c) men's powerlifting results, and (d) women's powerlifting results. Second-order polynomial curve fits are displayed (solid line) together with associated coefficient of determination (R^2).

However, a detailed inspection of scatter plots of residuals *vs*. ln M (Figure 2) shows a curvilinear relationship for all allometric models, except for women's PL results. In particular, a moderate to strong non-linear relationship was found between raw residuals and ln M ($R^2 = 0.20–0.59$, $p<0.05$) for men's and women' WL and men's PL performances. These results clearly indicate that the allometric model applied to all lifting performance, except in women's PL, exhibit a favourable bias toward lifters in middleweight classes.

Discussion

The present study examined the allometric and second-order polynomial relationship between lifting performances in both WL and PL on the one hand, and M on the other. Performance in WL and PL certainly represent the maximum of achievable physical strength, so that it seems justified to call these performances 'maximal strength'[25]. The theory of geometric similarity suggests that maximum muscle strength (S) should scale to M to the 2/3 power (i.e., $S \propto M^{0.67}$), also known as isometric scaling[1,6]. In our study, mass exponents b for the men's and women's WL performances were 0.61 and 0.68. For PL performances, gender-specific mass exponents b were 0.69 for men and 0.80 for women. While women's WL and men's PL performance appeared to scale in line with theory of the geometric similarity, men's WL performance scale with negative allometry, and women's PL performance scale with positive allometry, respectively.

Modelling both WL and PL results in this study did not include men over 105 kg (over 110 kg for PL) and women over 75 kg. Therefore, possible confounding factor of disproportionate increase in body fat, common in the overweight subjects [26,27] (i.e., super heavyweight categories), was excluded from the analyses. In addition, a relatively similar number of lifting performances (between 70 and 90) was analyzed in both WL and PL. Still, the obtained mass exponents varied from 0.61 to 0.80, suggesting that other factors than body composition and sample size might have had significant influence on the lifting performance – body mass relationship. Comparisons of the allometric exponents b obtained in this study also raised two important questions: a) *Why do women have significantly higher mass exponents in both WL and PL than men,* and b) *Why do PL performances have significantly higher mass exponents than WL performances?*

Regarding the first question, significantly higher mass exponents obtained in the women's WL and PL results can be attributed to several factors. First, it must be underlined that WL and PL for women is a relatively new sport event, when compared to men's WL and PL. For example, 72 men's and only 15 women's World Championships in WL were held until the present date. It is, therefore, feasible to expect that men's lifting performance exhibit more homogeneity within body weight classes. Figure 1a confirms this assumption, showing greater dispersion in WL results of women than of men. Thus, defined heterogeneity in strength across body weight classes in women can decrease the possibility to define a true relationship between lifting performance and M. The second explanation is based on the fact that women generally tend to have less active muscle mass[28] and more fat tissue (i.e., different body composition) than men[29–31] regardless of the body-weight class analyzed. Moreover, it has been demonstrated that women generally have more fat-free mass in their lower body than men do. It is therefore, likely that the observed gender-specific relationship between muscle strength and M could be the result of gender differences in body composition and regional distribution of contractile tissue. Finally, one cannot exclude possible use of illegal but non-detectable drugs of a higher prevalence among one gender over another (e.g., growth hormones[11]).

Regarding the second question, the authors recognize two possible explanations for PL performances having significantly higher mass exponents than WL performances. The first explanation is related to technical and biomechanical differences between WL and PL events. Namely, WL events (snatch and clean-and-jerk) are far more complex movement patterns than PL events (bench press, squat and dead lift). Therefore, besides raw muscle strength, specific lifting skill has a profound influence on the performance in WL. It is not uncommon that a weightlifter misses the maximum lift due to a small technical error at the end of the lift (e.g., loss of balance). In that case, athlete's overall lifting performance would not represent his/her true maximum strength capabilities. Since characteristic motor-skill influences WL performance more than PL performance, the stated differences in the relations between M and performances are easy to follow.

It must also be pointed out that the WL performance depends on several other motor abilities besides strength, like power, speed, flexibility and coordination, which do not scale with M similarly as muscle strength. Several authors[7,10,32] have pointed out that the WL performances should be recognised as a combined measure of strength, power and skill, while PL performance is a pure measure of strength. Thus, lower mass exponent b for the WL performance when compared to the PL performance could be the result of the abovementioned structural and functional differences between these two lifting techniques.

The second explanation is related to grip strength. Namely, in both WL disciplines (snatch and clean-and--jerk) an athlete pulls the barbell up from the floor by holding it with his/her palms. It can be, therefore, expected that grip strength may be one of the limiting factors for success in WL. In PL, only one lifting discipline is related to grip strength – it is dead lift. Thus, the overall performance in PL is probably to a smaller degree influenced by the grip strength than the performance in WL. Vanderburgh and Batterham[11] also reported similar finding. Since grip strength scales to M with negative allometry in both men and women[15,16], differences in mass exponent b between WL and PL could be also the result of the specific influence of grip strength on lifting performance in WL and PL.

Another important finding of this study is related to regression diagnostics of the allometric and second-order polynomial model applied to the WL and PL data. Analysis of residuals showed that allometric modeling for *M* does not provide an appropriate fit for men's and women's WL and men's PL results. In particular, the results have shown that the allometric modeling exhibit a favourable bias toward athletes in middleweight classes. Results of the present study also confirmed previous findings[10,21] that the second-order polynomial model provides statistically superior solution when modeling lifting performances for differences in *M*. However, in agreement to the results of Vanderburgh and Dooman[21], the authors have found no satisfactory explanation for the superiority of the second-order polynomial model other than its better statistical fit. Several research studies[10,11,21] have demonstrated that allometric modeling is statistically incorrect when used to scale the WL and PL performances for *M*. However, as far as we could ascertain, most researchers did not provide a possible biological explanation for the results obtained. Vanderburgh and Batterham[11] revealed that half as many powerlifters are found in the lightest and heaviest weight classes as in the intermediate classes and that intermediate classes' top lifters are perhaps more likely to achieve at a higher body mass adjusted level than those powerlifters in lower and higher classes. However, this explanation cannot be applied to the WL results.

A possible biological explanation for an inappropriate fit of the allometric model in the WL and PL performances could be related to a violation of the presumption of geometric similarity among lifters. For example, it is common that lifters in both sport events move to a higher weight class by increasing his/her muscle mass, especially in the middleweight classes. In this case, lifters with similar heights and other linear body dimensions would have disproportionately greater limb girths and body masses. It would be, therefore, advisable to include more anthropometric measures (e.g., height) in the analysis when modeling lifting performance (or any other physiological or performance variable) for differences in body size as suggested by Nevill[33]. Recently, Ford et al.[34] have shown that muscle mass, but not *M*, varies almost exactly with the cube of height over the entire range of body size of weightlifters, so that strength varies almost exactly with height squared or with muscle mass to the two-thirds power. Ford et al.[34] have also showed that the fraction of *M* devoted to non-contractile tissue increases abruptly in heavier lifters. This abrupt transition produces corners in the curves relating performance variables to *M*, and these corners preclude a good fit by any continuous allometric function relating a power of *M* to measures of strength[34]. More recently, Nevill et al.[35,36] provided evidence that athletes' physiques could substantially deviate from geometric similarity and concluded that this deviations have serious implications for the allometric scaling of physiological and performance variables. In particular, Nevill et al.[35,36] proposed the use of corrected limb girths (e.g., thigh, calf) instead of *M* in the allometric scaling of human biological functions. These data suggest that other indices of body size, like height, fat-free mass or muscle mass should be used when modeling muscle strength for body size.

Conclusion

To summarize, our result together with some previous data[8,10,11,21] indicate that the allometric modeling of WL and PL results for *M* does not provide size-independent index of lifting performance. Instead, it exhibits a favourable bias toward middleweight lifters in most lifting data analyzed. The possible explanations for this inappropriate statistical fit of the allometric model applied to the WL and PL data are: 1) lifters have disproportionately greater limb girths than bone lengths, thus violating the presumption of geometric similarity, and 2) muscle mass does not represent a constant proportion of body mass within the sample of elite lifters. Moreover, we demonstrated that WL and PL results scale differently for *M* possibly due to their structural and functional differences (i.e. PL is a pure strength sport, while WL is strength-speed sport with strong emphasis on specific and rather complex lifting skill). Finally, we showed that the allometric relationship between lifting performance in both WL and PL is gender-specific, probably due to gender differences in body composition and regional distribution of contractile tissue. Based on these results we suggest using muscle mass (or fat-free mass) and height as indices of body size when modeling WL and PL performances. This would allow comparisons of size-independent lifting performance (separately for WL and PL) of all lifters, regardless of weight category (i.e. super heavyweight athletes included) and gender. These findings together recent observations obtained on other human populations[35,38,39] highlight the importance of using more suitable indices of body size than M when comparing physiological performance of humans of different body size.

Acknowledgments

The authors wish to thank the reviewers for their constructive comments and critiques. This study was supported in part by grant from Croatian Ministry of Science, Education and Sport.

REFERENCES

1. JARIC, S., Sports Med., 33 (2002) 615. — 2. BOMPA, T. O.: Periodisation: theory and methodology of training. (Human Kinetics, Champaign, 1999). — 3. STONE, M. H., W. A. SANDS, K. C. PIERCE, J. CARLOCK, M. CARDINALE, R. U. NEWTON, Med. Sci. Sports Exerc., 37 (2005) 1037. — 4. JARIC, S., D. MIRKOV, G. MARKOVIC, J. Strength Cond. Res., 19 (2005) 467. — 5. SEKULIC, D., N. ZENIC, G. MARKOVIC, Coll. Antrop., 29 (2005) 723. — 6. CHALLIS, J. H., J. Strength Cond. Res., 13 (1999) 367. — 7. DOOMAN, C. S., P. M. VANDERBURGH, J. Strength Cond. Res., 14 (2000) 32. — 8. KAUHANEN, H., P. V. KOMI, K. HAKKINEN, J. Strength Cond. Res., 16 (2002) 58. — 9. NEVILL, A. M., R. L. HOLDER, J. Appl. Physiol., 79 (1995) 1027. — 10. BATTERHAM, A. M., K. P. GEORGE, J. Appl. Physiol., 83 (1997) 2158. — 11. VANDERBURGH, P. M., A. M. BATTERHAM, Med. Sci. Sports Exerc., 31 (1999) 1869. — 12. McMAHON, T.A.: Muscles, reflexes, and locomotion. (Princeton University Press, New Jersey, 1984). — 13. ASTRAND, P. O., K. RODAHL: Textbook of work physiology. (McGraw Hill, New York, 1986). — 14. JARIC, S., D. UGARKOVIC, M. KUKOLJ, J. Sports Med. Phys. Fitness, 42 (2002) 141. — 15. MARKOVIC, G., S. JARIC, Eur. J. Appl. Physiol., 92 (2004) 139. — 16. VANDERBURGH, P. M., M. T. MAHAR, C. H. CHOU, Res. Q. Exerc. Sport, 66 (1995) 80. — 17. CROUCHER, J. S., Res. Q. Exerc. Sport, 55 (1984) 285. — 18. HESTER, D., G. HUNTER, K. SULEVA, T. KEKES-SZABO, Nat. Strength Cond. Assoc. J., 12 (1990) 54. — 19. HUNTER, G., D. HESTER, S. SNYDER, G. CLAYTON, Nat. Strength Cond. Assoc. J., 12 (1990) 47. — 20. LIETZKE, M. H., Science, 124 (1956) 486. — 21. VANDERBURGH, P. M., C. S. DOOMAN, Med. Sci. Sports Exerc., 32 (2000) 197. — 22. JENSEN, K., L. JOHANSEN, N. H. SECHER, Eur. J. Appl. Physiol., 84 (2001) 201. — 23. FRANKE, W. W., B. BERENDONK, Clin. Chem., 43 (1997) 1262. — 24. SINCLAIR, R. G., Can. J. Appl. Sport Sci., 10 (1985) 94. — 25. TITTEL, K., H. WUTSCHERK, Anthropometric factors. In: KOMI, P. V. (Ed.): Strength and power in sport. (Blackwell Scientific Publications, London, 1992). — 26. GREIL, H., U. TRIPPO, Coll. Antropol. 22 (1998) 345. — 27. TRIPPO U., H. GREIL, Coll. Antropol. 22 (1998) 365. — 28. ALWAYS, S. E., W. H. GRUMBT, J. STRAY-GUNDERSEN, W. J. GONYEA, J. Appl. Physiol., 72 (1992) 1512. — 29. WILMORE, J.H., Med. Sci. Sports. Exerc., 15 (1983) 21. — 30. HAJNIS, K., J. PARIZKOVA, R. PETRASEK, Coll. Antropol., 27(2003) 563. — 31. KATIC, R., Coll. Antropol., 27 (2003) 351. — 32. NEWTON, R. U., W. J. KRAEMER, Strength Cond., 14 (1994) 20. — 33. NEVILL, A. M., J. Appl. Physiol., 77 (1994) 2870. — 34. FORD, L. E., A. J. DETTERLINE, K. K. HO, W. CAO, J. Appl. Physiol., 89 (2000) 1061. — 35. NEVILL, A. M., G. MARKOVIC, V. VUCETIC, R. HOLDER, Ann. Hum, Biol., 31 (2004) 436. — 36. NEVILL, A. M., A. D. STEWART, T. OLDS, R. HOLDER, Am. J. Phys. Anthrop., 124 (2004) 177. — 37. ATKINS, S. J., J. Strength Cond. Res., 18 (2004) 53. — 38. TOLFREY, K., A. BARKER, J. M. THOM, C. I. MORSE, M. V. NARICI, A. M. BATTERHAM, J. Appl. Physiol., 100 (2006) 1851. — 39. NEVILL, A. M., R. HOLDER, G. MARKOVIC, J. Appl. Physiol., 101 (2006) 1152.

G. Marković

Faculty of Kinesiology, University of Zagreb, Hovaćanski zavoj 15, 10000 Zagreb, Croatia
e-mail: gmarkov@ffk.hr

MODELIRANJE UTJECAJA VELIČINE TIJELA NA NATJECATELJSKE REZULTATE U OLIMPIJSKOM DIZANJU UTEGA I »POWERLIFTINGU«

SAŽETAK

Glavni cilj ovog istraživanja bio je utvrditi 1) da li natjecateljski rezultati u olimpijskom dizanju utega (WL) i »powerliftingu» (PL) skaliraju sa tjelesnom masom (*M*) u skladu s teorijom geometrijske sličnosti, i 2) da li postoje razlike među spolovima u alometrijskoj povezanosti između dizačkih rezultata i veličine tijela. U tu svrhu analizirano je deset najboljih rezultata u WL i PL u svakoj težinskoj kategoriji osim super-teške, postignutih u razdoblju 2000–2003. Podaci su analizirani primjenom alometrijskog modela te polinomijalnog modela drugog stupnja, dok je provjera o primjerenosti primijenjenih modela provjerena detaljnom regresijskom dijagnostikom. Rezultati istraživanja pokazuju kako 1) ženski rezultati u WL i muški rezultati u PL skaliraju s *M* sukladno teoriji o geometrijskoj sličnosti, 2) postoje značajne spolne razlike u alometrijskoj povezanosti između dizačkih rezultata u oba sporta i *M*; te su razlike vjerojatno rezultat spolnih razlika u kompoziciji tijela, 3) rezultati u WL i PL skaliraju s *M* različito vjerojatno zbog strukturalnih i funkcionalnih razlika koje postoje među njima. Međutim, alometrijski eksponenti dobiveni u ovom istraživanju ne omogućuju definiranje indeksa rezultata u WL i PL koji su nezavisni od veličine tijela iz razloga što alometrijski model favorizira rezultate kod dizača u srednjim težinskim kategorijama kod većine analiziranih podataka. Zbog mogućih devijacija u geometrijskoj sličnosti dizača utega, buduća istraživanja o skaliranju rezultata u WL i PL trebala bi koristiti nemasnu masu tijela i tjelesnu visinu kao pokazatelje veličine tijela.