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Non Linear Anthropometric Predictors in Swimming

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A B S T R A C T

In this paper we have tried to identify the significance and character of the linear and non-linear relations between simple anthropometric predictors: body height (BH), body weight (BW), and body mass index, and swimming performance: freestyle swimming 50 (FS50) and 400 meters (FS400), in a sample of young (15 years old on average) male (N=40) and female (N=28) swimmers. Linear (general model: y=a+bx) and nonlinear regression (general model: y= a+bx+cx²) were calculated simultaneously. Morphological variables are a significantly better predictor of the FS50 in males (BH mostly), and FS400 in females (BW mostly). This study emphasized some of the main advantages in the non-linear regression calculation (including an interpretation of the relationships at a more superior level), and consequently allowed a precise anthropometric modeling in swimming using simple and easily measurable variables. For example, the best results in FS400 can be expected for the subjects that are average in BW (which guarantees solid muscle mass – the generator of force), but above average in BH (because of the physical law of lever). In conclusion, nonlinear regressions allow one to define the real nature of the relationships between variables, but only if compared with the linear ones. Additionally, this study emphasized one of the most important factors in defining possible specification-equation (e.g. structure of the influence of the different dimensions on the sport achievement) in different sports. In short, it underlines the importance of sampling the appropriate sample of the subject – highly skilled athletes exclusively.

Key words: *morphology, motor skill, nonlinear multiple regression, kinesiology, methodology*

Introduction

The relationships between the variables within different anthropological dimensions are a problem often investigated[1–6]. In most circumstances for such a purpose, linear correlation and regression analysis are calculated. On the other hand, nonlinear regression models are rarely used in anthropological sciences. But, some advantages of nonlinear regression calculations and interpretations are clearly demonstrated. Sekulic et al. (2003)[7] used a non linear model and explained the relationship between certain anthropological predictors and psycho-physiological exercise responses criteria in most cases when linear model failed to demonstrate significant relationship. In a more recent study[8], authors established nonlinear relationships between anthropometric and motor-endurance variables and concluded that the non linear – square relation between the variables can be expected and explained in two cases: (1) if there is evident cause (for example – a biomechanical and/or a physiological cause) why two absolutely different sub-groups of subjects should reach equal results in the criterion, and (2) if an established non linear relationship can be explained following some evident non-linear-square basis.

However, calculation of nonlinear regression models is still very rare in anthropology. Our belief is that some of the possible bases for such a situation are: a) nonlinear regression procedures are relatively unknown and rarely published, except in the strictly specified statistical and mathematical Journals[9,10], and b) nonlinear regressions are undoubtedly complex in the calculation but even more – in the interpretation. Therefore, even if they are aware of the certain benefits of the nonlinear models, investigators avoid using the complicated and »clumsy« nonlinear, when they can obtain quite interpretable and satisfying results using simple linear regressions. Such logic is understandable, although not entirely scientifi-

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cally justifiable. Basically, by using the linear models exclusively, investigators can make serious interpretative errors (see Sekulic et al. 2003 and 2005[7–8] for details). But, on the other hand, it is evident that nonlinear regressions have to be confirmed in their usefulness, and even more – the logics of the interpretation, to allow investigators to recognize their advantages and possibilities in some specific circumstances.

In one of the previously mentioned studies[8] the significant nonlinear square relationship between anthropometric predictors and motor-endurance criteria, in a sample of physically active males (N=300) have been established. Briefly, the body mass index (BMI) as a simultaneous indicator of body weight (BW) and body height (BH), was a significant predictor of the high-jump, push-ups, sit-ups, 1500 meters running, but also – 50 meters freestyle swimming (FS50). The investigation we refer to is performed on large, but – nonselected sample of subjects. In other words, the subjects were highly differentiated in the level of the characteristic motor-knowledge (e.g. motor skill), known to be highly important in performing criteria – motor endurance variables[2], particularly important in FS50. Namely, the assumption is (and the 1st hypotheses of the present paper) that the (nonlinear) prediction of the FS50 by simple anthropometric predictors (BH, BW, BMI) will be numerically higher and more interpretative if established on a sample of trained swimmers (swimming athletes, in this text – swimmers). Next (2nd hypotheses), such a (nonlinear) relationship should be numerically higher if the swimming distance is increased, because the eventual factors which determine the *anthropometric → swimming performance* (A→S) relationship which subsist over a shorter distance, will be »self-multiplied« for the longer swimming distance.

The aims of the present study were: (1) to calculate, interpret and compare the linear and nonlinear correlation between BH, BW and BMI as anthropometric predictors, and freestyle swimming over 50 meters (FS50) and 400 meters (FS400) in a sample of young swimmers (see Methods), and (2) to use some of the calculated significant linear and nonlinear predictors and establish a nonlinear multiple regression model which will hypothetically explain the greater proportion of the swimming criterion's variance.

Materials and Methods

Subjects: 68 young swimmers from the Adriatic region (14–16 years, mean age 15.2±3 years±months), all in good health and top season form, served as the sample of subjects. The subjects received a complete explanation of the purpose and the procedures of the study and gave their informed consent. Since we had to collect a relatively large sample of trained swimmers of the same age, but also – of high competitive national level (National Championship participants), the measuring and sampling was performed over two years. First group of 35 swimmers (born in 1989) was tested in February 2005, and the second one (32 swimmers, born in 1990) in February 2006. The sample was divided into two groups, males (N=40) and females (N=28). All of them had been active in swimming sport for 7–9 years, performing 6–8 training sessions per week in the last two years, and none of them reported any recent injuries.

Variables: The sample of variables consisted of two sets: three anthropometric variables (body weight – BW, body height – BH, and body mass index – BMI), and two swimming ability variables: 50 meters freestyle swimming – FS50, and 400 meters freestyle swimming – FS400. We measured FS50 as a short distance and FS400 as a long distance (for such an age) swimming variable. Each subject performed the anthropometric and swimming testing within the same week. BW and BH were measured with standard techniques[4,7] to the nearest 0.1 kg and 0.5 cm, respectively. BMI was calculated as follows: $BMI = BW(kg)/[BH(m)]^2$. Swimming results were electronically obtained at the local competition, following the FINA procedure[8].

Data processing methods: We calculated descriptive statistics for all the variables. Linear and non-linear correlations were calculated between the anthropometric variables and swimming variables. The general non-linear square function equation used was: $y = a+bx+cx^2$, where »*y*« re presents the criterion – one of the analyzed swimming variables), and »*x*« represents the predictor – one of the anthropometric measures. All coefficients were considered significant at a level of 0.95 ($p<0.05$). Statsoft's Statistica version 6.0 was used for all the statistical procedures.

Results

Descriptive statistics are presented in the Table 1. All variables can be considered as normally distributed, by means of Kolmogorov-Smirnov's test.

As presented in the Table 2 all three anthropometric measures are in most cases significantly correlated with FS50 and FS400, linearly and nonlinearly. In addition, evident is certain differential influence of the anthropometrics on swimming performance. Accordingly, anthropometric variables superiorly explain FS50 in males, and FS400 in females. Also, linear relation BH→FS50

TABLE 1
DESCRIPTIVE STATISTICS – MALES

	Males		Females	
	X	SD	X	SD
BH (cm)	168.55	5.18	160.70	4.32
BW (kg)	56.45	4.82	49.67	3.82
BMI (kg/m²)	19.57	2.10	18.98	1.38
FS50M (s)	30.23	2.12	33.25	1.96
FS400M (min:s)	5:21	0:11	5:48	0:14

BH – body height, BW – body weight, BMI – body mass index, FS50M – freestyle swimming 50 meters, FS400M – freestyle swimming 400 meters

TABLE 2
LINEAR AND NON LINEAR REGRESSION MODELS BETWEEN ANTHROPOMETRIC PREDICTORS AND SWIMMING CRITERIA

Criteria	Predictor	Model	R	R^2	A	B	C
FS50M (males)	BH	LINEAR	0.73*	0.53*	57.27*	–0.16*	
		NON LINEAR	0.73*	0.53	91.48	–0.57	0.00
	BW	LINEAR	0.63*	0.40*	37.12*	–0.12*	
		NON LINEAR	0.70*	0.48*	49.96*	–0.58*	0.00*
	BMI	LINEAR	0.39*	0.15*	38.13*	–0.40*	
		NON LINEAR	0.56*	0.31*	90.49*	–5.60*	0.13*
FS400M (males)	BH	LINEAR	0.56*	0.32*	9.62*	–0.03*	
		NON LINEAR	0.57*	0.33*	20.94	–0.16	0.00
	BW	LINEAR	0.44*	0.19*	6.22*	–0.02*	
		NON LINEAR	0.57*	0.32*	9.58*	–0.14*	0.00*
	BMI	LINEAR	0.23	0.05	6.18*	–0.05	
		NON LINEAR	0.52*	0.27*	19.17*	–1.34*	0.03*
FS50M (females)	BH	LINEAR	0.58*	0.34*	53.31*	–0.13*	
		NON LINEAR	0.64*	0.41*	153.26*	–1.42	0.00
	BW	LINEAR	0.58*	0.34*	39.98*	–0.14	
		NON LINEAR	0.74*	0.54*	60.54*	–1.08*	0.01*
	BMI	LINEAR	0.51*	0.26*	45.75*	–0.66*	
		NON LINEAR	0.64*	0.40*	114.49*	–8.27*	0.21*
FS400M (females)	BH	LINEAR	0.72*	0.52*	10.54*	–0.03*	
		NON LINEAR	0.72*	0.52*	10.43	–0.03	0.00
	BW	LINEAR	0.72*	0.52*	7.22*	–0.04*	
		NON LINEAR	0.76*	0.58*	8.90*	–0.11	0.01*
	BMI	LINEAR	0.60*	0.36*	8.45*	–0.16*	
		NON LINEAR	0.64*	0.41*	17.08	–1.11*	0.03

BH – body height, BW – body weight, BMI – body mass index, FS50M – freestyle swimming 50 meters, FS400M – freestyle swimming 400 meters, R – coefficient of the correlation, R^2 – coefficient of the determination, A – interception coefficient, B – linear coefficient, C – curvature coefficient, *$p<0.05$

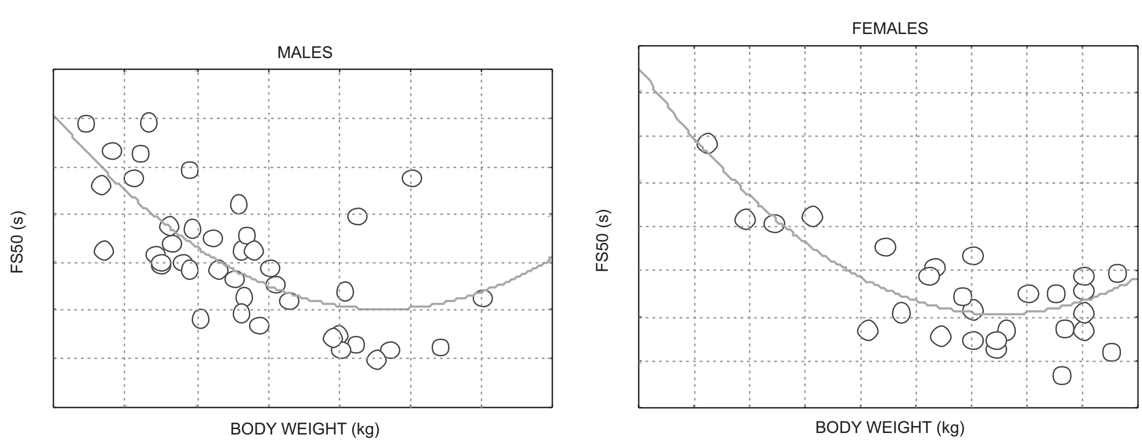

Fig. 1. Non linear correlation model for the variables: Body Weight and 50 meters freestyle swimming (FS50) in males and females.

reached the highest predictive value in males. At the same time, nonlinear model BW→FS400 explains the most of the common variance in the sample of young female swimmers.

In Figures 1, 2 and 3 some characteristic linear and nonlinear regressions are presented. Those relationships are selected since in forthcoming Discussion will be used as presenters of the characteristic explanations in defining the true logics and nature of the nonlinear and linear predictions of the swimming performance.

But, it must be stressed that we will interpret and discuss only those nonlinear relations where the nonlinear

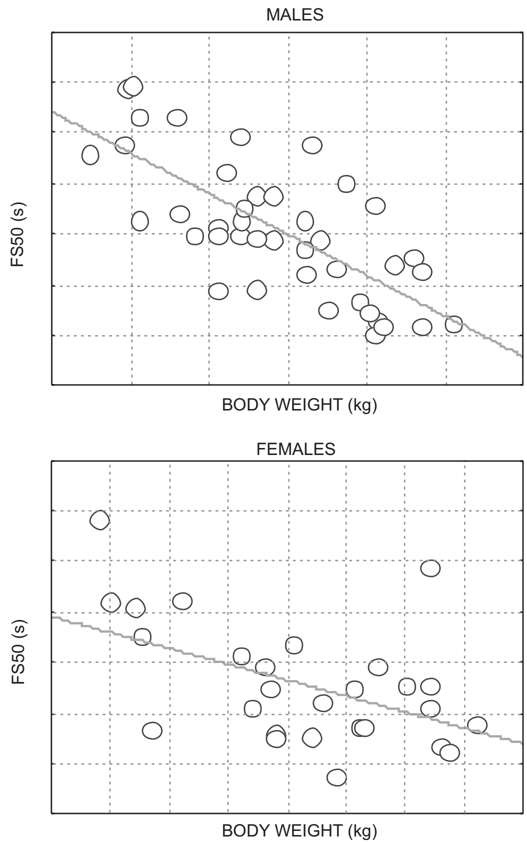

Fig. 2. Linear correlation model for the variables: Body Height and 50 meters freestyle swimming (FS50) in males and females.

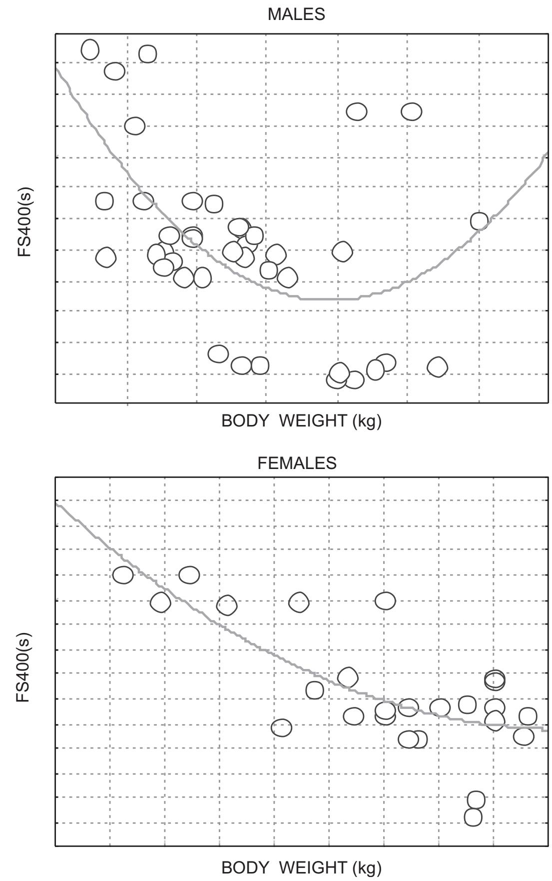

Fig. 3. Nonlinear correlation model for the variables: Body Weight and 400 meters freestyle swimming (FS400) in males and females.

coefficient (»C« in Table 2) is significant, no matter the eventual difference of the explained variance in linear and matching nonlinear regression. It must be pointed out because if non linearity is aimed at, the key-parameter which should be observed is the non linear-equation-element. Generally, if the non-linear-equation-element is not significant, it practically »linearizes« the non linear equation.

Discussion

Relationships between anthropometrics and swimming achievement in different samples

From the results presented in the table 2 it is obvious that anthropometric variables predict swimming results more significantly in the trained sample (athletes), comparing to non-athletes[8]. Generally, it is not hard to explain. The sample of subjects we used in our study has a very similar swimming technique (e.g. their technique is excellent). In other words, if the swimming technique is not a component which differentiates the subjects in their swimming results – the greater part of the variance remains to be explained by other dimensions. In our case it allowed determination of the anthropometrics' influence on the swimming achievement. Basically, the most significant linear anthropometric predictor of swimming performance is BH. The linear relationship between BH and swimming performance can be explained simply. A more pronounced BH defines longer extremities[11], while longer extremities allow one to: perform fewer arm strokes for the same distance[12,13], but also to achieve a higher moment of force (MF) in the single stroke because of the law of levers ($MF=F \cdot a$). In our case, the »F« is force applied during a single arm stroke, and »a« is the distance between a single joint and connection-point of the active muscles on the bone (lever). Naturally, »a« increases with BH, which is followed by an increase in MF, all allowing one to perform more effectively in FS50. Of course, all said can be expected only if BH is followed by BW, in other words – muscle mass (MM) as a generator of force.

Therefore, the 1st hypotheses of our work is already practically confirmed since the morphological variables are a significantly better predictors of the swimming result in the sample of swimmers (trained athletes), than in previously studied[8] non-athletes.

What leads to the differential influence of the anthropometrics on swimming in males (a better prediction of the FS50) compared to females (better prediction of the FS400)? It is well known that strength is related to MM[14]. Also, studies have confirmed that the result in short distance (but not long distance) swimming is directly influenced by different strength manifestations[15]. These two facts allow us to expect that MM positively influence FS50. Therefore, since males are more differentiated in MM than females[16,17], the more pronounced prediction of the FS50 in males is clear.

Consequently, the second hypotheses of our work can be partially accepted, since morphological influence is more pronounced in FS400 than in FS50, but only in the sample of female swimmers, probably because of the higher homogeneity of the morphological structure in females than in males[11,16,17].

Relationships between anthropometrics and swimming achievement calculated by linear and nonlinear model

In the following text we will compare some of the most interesting linear and nonlinear regressions established. Figure 1 presents nonlinear BW→FS50 relationship in males and females. The relationship between these two variables in both samples can be recognized as – the positive influence of the increase of the BW on the FS50 result, but – no more than one specific level (breakpoint), where the regression curve slightly changes direction and transforms from a »positive« into »negative influence«. Such a »positive-changing-to-negative« (and opposite) relation is not rare in nonlinear regressions, and actualizes one of the most important advantages of the nonlinear regression models. Briefly, in some cases, linear correlation is not significant because the scatterplot forms a »parabolic« shape. In such cases, linear correlation can neither calculate the significant positive, nor negative relationship because both exist. In the left part of the scatterplot exists one (for example – positive), while on the right side of the scatterplot is – another (negative)[7]. What in fact illustrates the nonlinear relationship between BW and FS50? In a homogenous sample of athletes, body weight is commonly an indicator of the active MM[18,19]. But, biologically and metabolically, it is impossible to increase MM above some optimal level[20]. Consequently, an increase of the BW, while it relates to MM increase significantly positively influences a short distance swimming result, but after the breakpoint (where an increase in the BW is practically defined by body fat increase), it negatively influences the swimming performance.

The next question is, why do linear (!) model superiorly predict the swimming performance in males, while the nonlinear (!) model superiorly predict the swimming performance in females? In Figure 2, the differences in the linear relation BH→FS50 in males and females are observed. The slope of the regression line is more pronounced in males than in females, numerically evident as the difference in the explained variance of the criterion. The authors are of the opinion that such a difference in the relation has to be explained on the basis of the difference in the MM where males of such are dominant comparing to females. Briefly, it is well known that an increase in BH increases MM in a more pronounced dynamic in males, than in females. Growth and developmental studies[21] performed on 16-year-old children (age of the sample of subjects in our study) reported 0.32 kg of the fat-free-mass (in other words – MM) per one centimeter of the BH in boys, and only 0.26 kg/cm in girls. In swimming, it relates to a stronger stroke, and therefore – better swimming performance, especially over short distances in males comparing to females. On the other hand, in females, the increase in BH is not as beneficiary (in terms of the MM increase). Simplified, for girls, »more BH« means only – »more BH«, and not necessarily – »more MM« (as in males), and therefore not necessarily – a better performance in swimming. Next, human extremities are »double lever«, where one lever is active in the force production (part of the bone between the muscle connection point and a joint), and the other lever is also active (part of the bone between muscle connection point a top of the toe/finger), but in the application of force. Figuratively speaking, if MM does not follow a BH increase, the increase in the length (e.g. BH) is not of great benefit, because both sides of the »lever« grow in the same way. From all this is clearly affirmed through BW→FS400 relationship (Figure 3). FS400 is an »endurance«, and not a »strength« discipline. Therefore, the nonlinear model BW→FS400 explains 13% variance more than linear the one in males. The difference is even more observable in females. The nonlinear model BW→ FS400 explains 20% more (!) of the common variance than the linear one. Anyone who understands swimming at a more superior level knows what this means, and why such a difference is obvious in longer distance, and not so noticeable in short distance swimming. In swimming, amount of air in the lungs – keeps the swimmer on the water's surface. This is directly related to lung volume, which are in humans grows more as a function BH than as a function of age[21], with no significant sex differences. In long distances, diffusion of the oxygen in the muscles gradually increases (because of the advanced acidosis and necessity of lactate metabolizing)[20]. It consequently decreases the buoyancy, increases the submersed body area, and finally – increases resistance during swimming. Such an occurrence is more pronounced in subjects with larger BW because: (1) these persons regularly have a larger MM and therefore – a higher oxygen need, and (2) lung volume does not grow as a function of the BW but as a function of the BH. Because of both these reasons, men are in a »worse« situation than women. Of course they swim faster when compared to women (because of the generally higher lung capacity, longer extremities, etc), but an increase in the BW will affect their FS400 performance more negatively than in women. Therefore, BW→ FS400 regression is more »curved« in males than in females.

Relationship between anthropometrics and swimming achievement calculated using the combined linear- nonlinear multiple regression

Finally, we have selected some linear and nonlinear simple predictors and calculated combined linear-nonlinear multiple regression. The results are presented in Figure 4 and Table 3.

As presented in Table 3, linear and nonlinear multiple regressions are significant ($p<0.05$). Accordingly, because of the (1) numerically higher coefficient of the determination, (2) non significant regression elements in the linear model, and (3) the significant non linear element (»*d*«), the relationship between the predictors and criterion should be interpreted using the non linear model. However it would not be possible separated from the graphic presentation of the calculated regression (Figure 4).

BW influences criterion (FS400) linearly, and BW non linearly. In short, the best results with the criterion can be expected for the subjects that are average in BW, but above average in BH (the approximate position of the »best-performers« is marked with »B« on the graph). The main reasons for such a statement – these subjects can use their expressed BH (see before – where we explained the relationship between BH and swimming performance), but only if the BW is average (average BW guarantees a solid MM which is the generator of force). In contrast, the »poor-performers« are characterized by (1) low BH and high BW (point »W1« on the graph), and/or (2) low BH and low BW (point »W2« on the graph). These subjects probably have (1) a relatively large quantity of fat tissue – ballast mass[11,16], which is definitely a burdening factor in freestyle performance, and/or (2) not enough muscle mass to perform the stroke effectively.

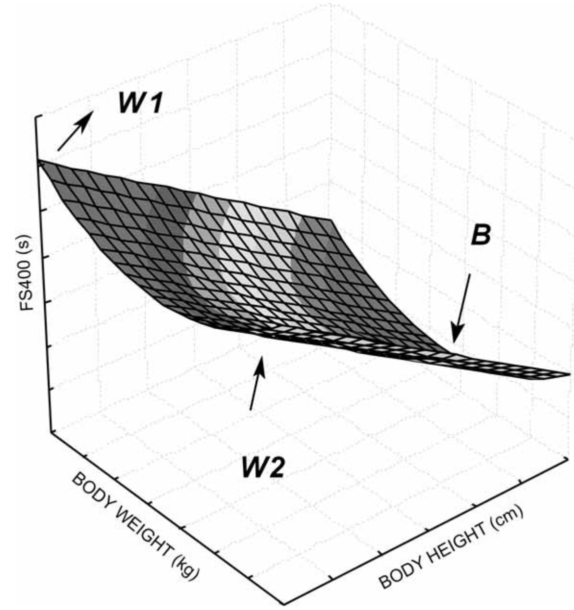

Fig. 4. Graphical presentation of the non linear multiple regression. Best performers' positioning – B, worst performers' positioning – W1 & W2, FS400 – freestyle swimming 400 meters.

Conclusion

In conclusion:

- Morphological variables are a significantly better predictor of a swimming result in a sample of swimmers (trained athletes), than in non-athletes. Authors are of the opinion that such a difference is related to the lower variations in swimming technique in trained swimmers than in non-trained subjects. Therefore, we can conclude that the relationships between anthropological predictors and sport performances should be studied in selected and trained athletes exclusively.
- Morphological influence is more pronounced in FS400 than in FS50 only in the sample of female swimmers, probably because of the higher homogeneity of the morphological structure in females than in males.
- Data presented and discussed herein can be used in the sport-selection of the young swimmers. Briefly, BW should be used as convenient predictor in female, and BH in male swimmers, of such an age. Of course, there is a certain possibility that some other anthropometric measures predict swimming results even better than those we used herein (BW, BH, BMI), but it should be investigated in some forthcoming studies.
- In future studies it would be interesting to define and interpret some nonlinear relationships with other practical repercussions in sport-training and/or sport-tac-

TABLE 3
MULTIPLE LINEAR AND THIRD ORDER NONLINEAR REGRESSION INDICATORS IN FEMALES

Criterion	Predictors	Model	R	R^2	Element	
FS400		LINEAR	0.73	0.53	A	9.11*
	BH (x)				B	0.02
	BW (y)				C	0.02
FS400		NON-LINEAR	0.77	0.60	A	9.51*
	BH (x)				B	–0.01*
	BW (y)				C	–0.06*
	BW^3 (y^3)				D	0.00*

BH – body height, BW – body weight, FS400 – freestyle swimming 400 meters, R – coefficient of the correlation, R^2 – coefficient of the determination, A – interception coefficient, B – linear coefficient, C – curvature (second order) coefficient, D – curvature (third order) coefficient, * $p<0.05$

tics. As far as authors of this study know, apart from the data discussed herein, such data are not presented so far.

– It is evident that calculation of the nonlinear multiple regressions is rather complicated and rely on numerous simple nonlinear regressions which should be calculated previously. Therefore, it would be useful to adjust, and/or construct a sort of the specific statistical-mathematical software for the calculation of the nonlinear multiple regressions.

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NELINEARNI ANTROPOMETRIJSKI PREDIKTORI U PLIVANJU

SAŽETAK

U ovom članku pokušalo se utvrditi značajnost i karakter linearnih i nelinearnih relacija između jednostavnih antropometrijskih prediktora: tjelesne visine (TV), tjelesne mase (TM) i indeksa tjelesne mase, i plivačkih sposobnosti: plivanje slobodnim načinom na 50 metara i 400 metara (FS50 i FS400). Uzorak ispitanika sačinjavali su aktivni plivači (prosječne dobi 15 godina), dječaci (N=40) i djevojčice (N=28). Linearni model ($y=a+bx$) i nelinearni regresijski model ($y=a+bx+cx^2$) izračunavani su paralelno po spolovima. Rezultati ukazuju kako morfološke varijable značajno bolje opisuju rezultat na FS50 kod dječaka (najbolji prediktor je TV), a na FS400 kod djevojčica (najbolji prediktor je TM). Ovo istraživanja ukazalo je na neke od glavnih prednosti izračunavanja nelinearnih regresija (uključujući i interpretaciju rezultata na naprednijoj razini). Osim toga, istraživanje je omogućilo precizno modeliranje u plivanju, upotrebom jednostavnih i lako mjerljivih antropometrijskih varijabli. Primjerice, najbolji rezultati u FS400 mogu se očekivati kod plivača prosječne TM (kao pokazatelja zadovoljavajuće količine mišićne mase – generatora sile), uz istovremeno iznadprosječnu TV (uslijed pozitivnog utjecaja na krak sile – zakon poluge). Zaključno, utvrdilo se kako nelinearne regresije omogućavaju istraživačima definiranje prave logike povezanosti između varijabli, ali samo ukoliko se nelinearne relacije kompariraju s linearnima. Osim navedenog, ova je studija ukazala na potrebu da se u kod definiranja antropoloških jednadžbi specifikacije za pojedine sportske aktivnosti, nužno treba odabrati ispitanike koji se minimalno razlikuju u postignuću u sportskoj vještini (karakterističnom motoričkom znanju), koja se analizira.