

Performance prediction models based on anthropometric, genetic and psychological traits of Croatian sprinters

AUTHORS: Luciana Zaccagni¹, Barbara Lunghi², Davide Barbieri¹, Natascia Rinaldo¹, Sasa Missoni^{3,4}, Tena Šaric³, Jelena Šarac³, Vesna Babic⁵, Marija Rakovac⁵, Francesco Bernardi², Emanuela Gualdi-Russo¹

¹ Department of Biomedical and Specialty Surgical Sciences, University of Ferrara, Italy

² Department of Life Sciences and Biotechnology, University of Ferrara, Ferrara, Italy

³ Institute for Anthropological Research, Zagreb, Croatia

⁴ Strossmayer University, School of Medicine, Osijek, Croatia

⁵ Faculty of Kinesiology, University of Zagreb, Zagreb, Croatia

ABSTRACT: Elite athletes differ from each other in their characteristics according to their discipline. This study aimed to identify performance predictors in elite Croatian sprinters taking into consideration their anthropometric, psychological and genetic characteristics. One hundred and four elite Croatian sprinters (68 males and 36 females) participated in this study. Of them, 38 are currently competing in the 100-metre dash. The others are former sprinters. The participants underwent direct anthropometric assessment. Participants were also tested by means of the Competitive State Anxiety Inventory-2 and for ACE and ACTN3 polymorphisms. Multiple linear regression analysis was applied to identify the best model for performance prediction. Different models were developed for males and females. Anthropometric traits accounted for 44% of the variance in performance for males, 62% for females. Once other traits (psychological for females) were entered into the model, no additional contribution to the variance was observed. The most significant predictors of higher running velocity were bicristal diameter and foot dimensions in males, and leg length and clean one-repetition maximum in females. The findings suggest that performance in sprinters is associated with anthropometric characteristics, with biomechanical implications that may be used to provide a more complete evaluation of sprinters' performance.

CITATION: Zaccagni L, Lunghi B, Barbieri D et al. Performance prediction models based on anthropometric, genetic and psychological traits of Croatian sprinters. *Biol Sport*. 2019;36(1):17–23.

Received: 2018-05-23; Reviewed: 2018-06-23; Re-submitted: 2018-07-16; Accepted: 2018-08-15; Published: 2018-10-15.

Corresponding author:

Emanuela Gualdi-Russo

Department of Biomedical and

Specialty Surgical Sciences,

University of Ferrara, 44121

Ferrara, Italy.

Email: emanuela.gualdi@unife.it

Key words:

Sprint performance

Personal best

Anthropometry

Genetic polymorphisms

Competitive anxiety

INTRODUCTION

Human physical performance is a multifactorial phenotype influenced by numerous genetic and environmental factors [1, 2]. More specifically, an elite athlete is a rare combination of talent with adequate anthropometric and psychological characteristics, in a favourable genetic framework. In particular, joint structure and muscle architecture are fundamental for sprinting, especially in determining the functional roles of muscles during movements in which they rapidly shorten [3]. Body shape and composition reflect both endogenous and exogenous influences as best suited to a particular sport and as an adaptation to training demands. According to the concept of morphological optimization, the successful phenotypes in one sport may change over time in relation, for example, to changes in the competitive environment [4]. Anthropometric traits are known in the literature as determinants of athletic performance [4,5]. Greater fat-free mass (FFM) and reduced adiposity, less ectomorphy and more strength improved race performance in 100 m sprinters ac-

ording to a previous study [6]. Successful sprinters tend to be homogeneous in height and body mass, as highlighted by coefficients of variation of 2% and 9%, respectively [4].

Athletic performance is also affected by individual psychology. In particular, confidence, anxiety, motivation and their inter-relationships are distinctive of an athlete [7]. Mental skills training can have an important role in improving performance, helping to be mentally prepared and to maintain that particular mindset during the competition [8]. The efficacy of this training has been demonstrated in several sports [9,10]. Hence, in addition to a superior technique and fitness level, elite athletes possess excellent mental skills [11]. Also, the psychological response to stress and motivation for exercise may be affected by genetic variations [12].

In the last decade, many studies have tried to establish an association between athletic performance and the growing number of genetic variants [13]. There are contrasting results in the literature

concerning the angiotensin-converting enzyme (ACE), playing an important role in circulatory homeostasis. The insertion (I) allele of the ACE I/D (rs1799752) polymorphism seems to be associated with endurance-orientated events [14, 15], while an excess of the deletion (D) allele was found to be associated with performance in power-oriented sports such as short distance swimming and sprinting [16-18]. The *ACTN3* (α -actinin-3) R577X polymorphism (rs1815739) has been extensively studied with reference to the power performance [19], as skeletal muscles generate forceful contractions at high velocity in the presence of α -actinin-3 [20]. Higher frequencies of *ACTN3* 577RR genotype were found in elite power and sprint athletes [13, 19], although this is not always confirmed [21].

Despite the fact that the topic is of great interest, it has been only partially addressed, and there is still no consensus regarding the definition of prediction models that take into account the combined effect of the above factors on the performance of sprinters. Thus, the aims of this study were to investigate anthropometric, psychological and genetic characteristics of an elite sample of Croatian sprinters and to develop new models of performance, quantifying best predictor variables, separately in both sexes.

MATERIALS AND METHODS

Participants

The study was carried out on a sample of 104 Croatian sprinters: 36 females (mean age 37.0 ± 14.8 years) and 68 males (mean age

33.2 ± 12.8 years); both sexes included the same composition of competitive athletes (36%) and former athletes (the remaining 64%).

Only sprinters who competed at a national or international level in the 100 m were invited by the Faculty of Kinesiology of Zagreb University (Croatia) to take part in this study. The personal best (PB) time at the 100-m distance of the athletes was obtained from the official national database. After being informed about the investigation, the athletes volunteered for the research and gave their written informed consent. The study was approved by the Ethical Committees of the University of Zagreb (Croatia; recorded April 22, 2013) and conformed to principles identified in the Declaration of Helsinki.

Procedures

Anthropometric data included five body diameters (biacromial, bicristal, femur, humerus, and ankle diameters), lower limb and leg lengths, foot length, lateral malleolus height and anteroposterior (AP) distance from heel to the 1st metatarsal head. These traits were chosen among those considered to be important to track the athletes' performances because they have landmarks on the skeleton and minimal changes during aging, within the limits of instrumental error. As our study included active and former sprinters, somatometric and physiometric characters which have a well-known relationship with age (such as height, weight, skinfold thicknesses) were excluded from this study [22,23]. All measurements were taken by trained anthropometrists according to the techniques recommended by Weiner and Lourie [24] (Lee and Piazza for AP distance) [3] and

TABLE 1. Characteristics of the sample by sex.

Trait	Males (N=68)			Females (N=36)	
	mean	SD	p	mean	SD
100 m PB (s)	10.98	0.42	<0.001	12.28	0.42
Weight (kg)	76.9	5.6	<0.001	58.6	4.9
Biacromial diameter (cm)	41.9	1.8	<0.001	37.0	1.8
Bicristal diameter (cm)	29.4	2.0	<0.001	27.8	2.1
Humerus diameter (mm)	72.1	4.4	<0.001	62.1	4.1
Femur diameter (mm)	98.0	4.6	<0.001	87.6	4.8
Lower limb length (cm)	92.7	3.8	<0.001	86.1	3.0
Leg length (cm)	45.9	1.9	<0.001	41.5	1.6
Foot length (cm)	27.5	1.2	<0.001	24.7	0.9
Ankle diameter (cm)	7.8	0.4	<0.001	6.8	0.4
Lateral malleolus height (cm)	7.3	0.6	<0.001	6.6	0.8
AP distance from heel -1 st metatarsal head (cm)	20.3	0.9	<0.001	18.4	0.7
Clean 1RM (kg)	108.0	23.6	<0.001	62.2	17.9
Standing long jump (cm)	302.7	22.5	<0.001	261.8	20.0
Cognitive state anxiety (score)	15.7	4.3	<0.05	18.0	5.5
Somatic state anxiety (score)	18.9	4.7	n.s.	20.8	5.6
Self confidence (score)	25.1	4.5	n.s.	25.1	5.1

using specific equipment consisting of small and large calipers and an anthropometer (GPM, SiberHegner Ltd., Switzerland). In addition, each sprinter self-reported his/her body weight, barbell clean one repetition maximum (1RM) and standing long jump (SLJ) at the time of the personal best (PB).

The measurement of psychological characteristics was performed by applying the Competitive State Anxiety Inventory-2 (CSAI-2), a sport-specific state anxiety scale developed by Martens et al. [25], recalling the situation at the time of the PB as clearly as possible [25]. The scale divides anxiety into three components: cognitive state anxiety, somatic state anxiety, and self-confidence. Self-confidence tends to be the opposite of cognitive anxiety and is an important factor in stress management. The CSAI-2 consists of 27 items, 9 for each subscale; each item was rated on a 4-point Likert-type scale, resulting in scores ranging from a minimum of 9 to a maximum of 36. All items were positively stated except item 14, scored reversely in the analyses.

Genetic analysis was conducted in the Molecular Biology Laboratory of the Department of Life Sciences and Biotechnology (Ferrara University, Italy). The ACE I/D polymorphism was determined using the polymerase chain reaction (PCR) method as previously described [14]. To study the ACTN3 R577X polymorphism we performed PCR amplification using the forward 5'-GTTCTGTGTCAGGACTGCC-3' and reverse 5'-TGGTCACAGTATGCAGGAGG-3' primers, followed by the Ddel restriction analysis.

Statistical analyses

Distribution normality was assessed separately by sex (Kolmogorov-Smirnov test). Comparisons between sexes were performed using the t-test. One-way ANOVA was applied to compare sprinters' PBs among different genotypes.

Pearson's correlation was calculated for sprinters' anthropometric and psychological traits and their 100 m PB. Only significant traits

were used in the multiple regression analysis with PB as the dependent variable. Multicollinearity among predictor variables was examined using the variance inflation factor (VIF) (VIF values < 10 were considered acceptable). Values of P<0.05 were considered statistically significant. All statistical analyses were performed using Statistica software version 11.0 (StatSoft srl, Tulsa, OK).

RESULTS

Sprinters' characteristics by sex are presented in Table 1. As expected, male sprinters were faster, heavier and stronger than females on average. Moreover, they had larger diameters, and longer legs and lower limbs than females.

Regarding the Competitive State Anxiety Inventory-2 test, the cognitive state anxiety component had the lowest score and the self-confidence component had the highest score in both sexes. Females had higher scores in cognitive state anxiety (CSA, +13%: p<0.05) than males; somatic state anxiety (SSA) and self-confidence (SC) were the same in both sexes.

The genotype distribution for each polymorphism was consistent with the Hardy-Weinberg equilibrium. Regarding the ACE polymorphism, the most frequent genotype in the whole sample was ID (54 subjects, 52%), followed by DD (26 subjects, 25%) and II (24 subjects, 23%). The frequency of allele I was 49% and that of D allele was 51%. Regarding the ACTN3 polymorphism, the most frequent genotype was RX (53 subjects, 51%), followed by RR (32 subjects, 31%) and XX (19 subjects, 18%). The frequency of allele R was 56% and that of X allele 44%. No significant difference was observed in genotype distributions or allelic frequencies between sexes. However, the DD homozygote's frequency was almost double in males (29%) compared to females (17%).

Table 2 shows the PB times of male and female sprinters in 100 m by ACE and ACTN3 genotypes. No significant difference was detected.

TABLE 2. Analysis of variance of personal best (s) by ACE and ACTN3 genotypes in both sexes.

genotype	Males			Females		
	N	mean	SD	N	mean	SD
ACE						
DD	20	10.97	0.45	6	12.31	0.20
ID	33	11.00	0.41	21	12.24	0.42
II	15	10.95	0.42	9	12.38	0.55
ANOVA	F=0.06	d.f=(2; 63)	p=0.94	F=0.31	d.f.= (2; 31)	p= 0.73
ACTN3						
RR	20	10.96	0.53	12	12.29	0.46
RX	36	10.96	0.38	17	12.28	0.42
XX	12	11.08	0.32	7	12.30	0.39
ANOVA	F=0.41	d.f=(2; 63)	p=0.67	F=0.01	d.f.= (2; 31)	p= 0.99

TABLE 3. Correlations between 100 m personal best (s) and traits in males and females.

Trait	Males N=68		Females N=36	
	r	p	r	p
Weight	-0.196	0.114	0.018	0.920
Biacromial diameter	0.098	0.433	0.083	0.642
Bicristal diameter	-0.269	0.029	-0.110	0.535
Humerus diameter	0.022	0.861	0.006	0.972
Femur diameter	0.021	0.870	0.070	0.695
Lower limb length	0.093	0.458	0.274	0.117
Leg length	0.191	0.125	0.442	0.009
Foot length	0.294	0.016	0.276	0.114
Ankle diameter	0.021	0.864	-0.060	0.738
Lateral malleolus height	-0.246	0.047	0.121	0.496
AP distance from heel -1 st metatarsal head	0.179	0.150	0.382	0.026
Clean 1RM	-0.390	0.003	-0.615	0.002
Standing long jump	-0.346	0.007	-0.443	0.034
Cognitive state anxiety	0.105	0.406	0.355	0.039
Somatic state anxiety	0.053	0.674	0.238	0.175
Self confidence	-0.173	0.168	-0.227	0.196

Table 3 presents correlations between sprinters' traits and their performance (100 m PB) in both sexes. In males, PB was negatively correlated with bicristal diameter and lateral malleolus height and positively correlated with foot length. In females, PB was positively correlated with leg length, AP distance from heel to 1st metatarsal head, and CSA. In both sexes, PB shows a significant negative correlation with clean 1RM and SLJ.

Tables 4 and 5 show multiple regression analyses used to investigate whether 100 m PB could be explained by means of sprinter's characteristics, selected from those showing a significant association

with PB in bivariate correlation analysis, respectively in males and females. Multicollinearity did not occur between predictor variables.

In male sprinters (Table 4), bicristal diameter, foot length and lateral malleolus height were significantly predictive of PB in the multivariate analysis. The total explained variance was 44% in the first model. Considering individual variables, foot length was found to be one of the strongest predictors of PB. In females (Table 5), leg length and clean 1RM were significantly predictive of PB in the first model, while clean 1RM remained the only significant variable after adding psychological traits (second model). The total explained variance was 62% in the first (only anthropometric traits), and in the second model (anthropometric and CSA psychological components). When the individual variables were examined, clean 1RM emerged as the strongest predictor of PB in both models. Considering the values of R^2 obtained from multiple regression analysis, a type I error of 5% and a power of 80%, 20 females and 28 males would have been required; thus the present sample size is adequately powered to detect determinants of performance in sprint running.

TABLE 4. Predictors of 100 m personal best (s) in males: results of multiple regression analyses.

Variables	Model			VIF
	β	t	p	
Bicristal diameter	-0.39	-3.37	0.001	1.287
Foot length	0.55	4.78	<0.001	1.268
Lateral malleolus height	-0.33	-3.14	0.003	1.044
Clean 1RM	-0.03	-0.27	0.791	1.491
Standing long jump	-0.18	-1.64	0.108	1.165
R^2	0.50			
Adjusted R^2	0.44			
p	0.000002			

DISCUSSION

The main purpose of the present study was to develop models to predict performance in sprinters on the basis of anthropometric, psychological and genetic characteristics. To our knowledge, no study to date has examined these relationships in elite sprinters simultaneously.

The bivariate correlation of anthropometric and psychological characteristics in sprinting was sex-specific. In females, we found a

TABLE 5. Predictors of 100 m personal best (s) in females: results of multiple regression analyses.

Variables	Model 1				Model 2			
	β	t	p	VIF	β	t	p	VIF
Leg length	0.37	2.22	0.041	1.465	0.34	1.91	0.075	1.581
AP distance	0.29	1.82	0.088	1.313	0.27	1.64	0.122	1.353
Clean 1RM	-0.56	-3.41	0.004	1.410	-0.56	-3.36	0.004	1.410
Standing long jump	-0.02	-0.14	0.888	1.507	-0.03	-0.16	0.872	1.508
Cognitive state anxiety					0.11	0.72	0.482	1.207
R^2	0.70				0.71			
Adjusted R^2	0.62				0.62			
p	0.0005				0.001			

significant inverse correlation between performance and leg length, AP distance, and CSA. In males, our findings indicated a significant bivariate correlation between better performance and larger bicristal diameter, shorter foot length, and higher lateral malleolus height. In both sexes, we detected a significant correlation between performance and clean 1RM and SLJ. From an anthropometric point of view, the fastest female athletes had short legs and feet (in the tarsal and metatarsal areas), while the fastest male athletes displayed wide hips and short and high feet. The observed sex-related association depends on sex differences in body build, involving a different relationship between anthropometric characteristics and performance.

No psychological component was correlated with PB in males. In females, however, performance was negatively correlated with CSA. Female sprinters reported higher levels of anxiety than males, as in other sports [26,27].

No significant genotype association with PB was observed in either sex, consistent with Papadimitriou et al [18]. In that study, genotype-performance associations at longer distances (ACE ID in the 400-m sprint performance and of *ACTN3* R577X in the 200-m sprint performance) were found, but not in 100-m sprint performance.

The multiple regression analysis confirmed that some anthropometric traits are the best predictors of PB in sprinters according to the models considered (bicristal diameter, foot length and height of lateral malleolus in males and leg length and clean 1RM in females). The addition of the psychological variable (only in females) did not change the results or the explained variance, which was significant and similar in all models.

Previous research suggests some relationships between anthropometric parameters and athletic performance [28,29]. According to the current study, the apparent importance of anthropometric variables in running speed may have biomechanical implications. Although researchers have explored the general association between foot structure and ankle muscle strength [30], few studies have investigated foot and ankle structure and their correlation with func-

tional abilities in sprinting. A recent study indicated the influence of the foot proportions on running speed [31]. A study conducted by Lee and Piazza [3] on skeletal structure of the foot showed, through computer simulation, that longer toes prolonged the time of contact, giving greater time for increasing acceleration by the propulsive ground reaction force. The finding that there are shorter plantar-flexor moment arms and longer forefoot bones in sprinters suggests that foot proportions may influence the capacity for acceleration [32]. Though we did not measure these variables and did not compare sprinters' characteristics with non-sprinters' ones, the current study suggests that foot proportions and sizes of lower limb segments are involved: short foot, short AP distance heel-1st metatarsal head, and high lateral malleolus height were more favourable for speed race. A shorter leg length also proved to be favourable in female sprinters, in agreement with the results of Lee and Piazza [3].

This study supplied new evidence on 100 m sprint performance and the association between somatic, psychological and genetic data. The strength of this study lies in the direct measurement of several anthropometric traits by trained operators. Still, there were some limitations: weight, clean 1RM and SLJ at the time of the PB were self-reported, so they may have led to a bias in the results. The use of anthropometric traits which were considered not age-dependent may have excluded other potentially important characters for success in sprinting (stature, for example).

Although the generalizability of the results is limited as the data were collected exclusively from Croatian participants, the positive aspect is that elite-only sprinters (past and present) of the same nation (Croatia) were invited to participate in the research following a more rigorous approach, while previous studies considered sprint and power athletes from mixed sports disciplines and events [19,33,34]. Further research is needed to identify whether differences in foot proportions are crucial in sprinting ability and, in this case, whether they are caused by adaptation to training or have a genetic origin.

CONCLUSIONS

In conclusion, we found evidence of the association of anthropometry with performance in sprinting. In addition, our study provided some predictive models of performance. The results of our analyses demonstrate that a shorter foot in males and a shorter leg in females may be advantageous for the best sprint performance.

Acknowledgments

We thank all the participants for allowing this research to take place.

Conflict of interest declaration

The authors have no conflict of interests.

REFERENCES

1. Tsianos GI, Evangelou E, Boot A, Zillikens MC, VAN Meurs JBJ, Uitterlinden AG, Ioannidis JPA. Associations of polymorphisms of eight muscle- or metabolism-related genes with performance in Mount Olympus marathon runners. *J Appl Physiol*. 2010;108:567-574.
2. Grenda A, Leońska-Duniec A, Kaczmarczyk M, Ficek K, Król P, Cięszczyk P, Zmijewski P. Interaction Between ACE I/D and ACTN3 R577X Polymorphisms in Polish Competitive Swimmers. *J Hum Kinet*. 2014; 42:127-136.
3. Lee SS, Piazza SJ. Built for speed: musculoskeletal structure and sprinting ability. *J Exp Biol*. 2009; 212:3700-3707.
4. O'Connor H, Olds T, Maughan RJ, International Association of Athletics Federations. Physique and performance for track and field events. *J Sports Sci*. 2007;25:S49-60.
5. Barbieri D, Zaccagni L, Cogo A, Gualdi-Russo E. Body composition and somatotype of experienced mountain climbers. *High Alt Med Biol* 2012; 13:46-50.
6. Barbieri D, Zaccagni L, Babić V, Rakovac M, Mišigoj-Duraković M, Gualdi-Russo E. Body composition and size in sprint athletes. *J Sports Med Phys Fitness*. 2017;57(9): 1142-1146.
7. Sarkar M, Fletcher D. Psychological resilience in sport performers: a review of stressors and protective factors. *J Sports Sci*. 2014;32:1419-1434.
8. Gee CJ. How does sport psychology actually improve athletic performance? A framework to facilitate athletes' and coaches' understanding. *Behav Modif*. 2010;34:386-402.
9. Kim BJ. The effect of Psychological Skills Training on Mental Game and Golf Performance. *K J Sport Psych*. 2003; 14:213-233.
10. Lim TH, O'Sullivan DM. Case Study of Mental Skills Training for a Taekwondo Olympian. *J Hum Kinet*. 2016; 50:235-245.
11. Vealey RS. Mental skills training in sport. In: Tenenbaum G, Eklund RC, editors. *Handbook of sport psychology*. Hoboken, NJ: Wiley; 2007. p. 287-309.
12. Chen ZY, Jing D, Bath KG, Ieraci A, Khan T, Siao CJ, Herrera DG, Toth M, Yang C, McEwen BS, Hempstead BL, Lee FS. Genetic variant BDNF (Val66Met) polymorphism alters anxiety-related behavior. *Science*. 2006;314:140-143.
13. Ma F, Yang Y, Li X, Zhou F, Gao C, Li M, Gao L. The association of sport performance with ACE and ACTN3 genetic polymorphisms: a systematic review and meta-analysis. *PLoS One*. 2013;8: e54685.
14. Scanavini D, Bernardi F, Castoldi E, Conconi F, Mazzoni G. Increased frequency of the homozygous II ACE genotype in Italian Olympic endurance athletes. *Eur J Hum Genet*. 2002; 10:576-577.
15. Tobina T, Michishita R, Yamasawa F, Zhang B, Sasaki H, Tanaka H, Saku K, Kiyonaga A. Association between the angiotensin I-converting enzyme gene insertion/ deletion polymorphism and endurance running speed in Japanese runners. *J Physiol Sci*. 2010; 60:325-330.
16. Costa AM, Silva AJ, Garrido ND, Louro H, de Oliveira RJ, Breitenfeld L. Association between ACE D allele and elite short distance swimming. *Eur J Appl Physiol*. 2009; 106:785-790.
17. Cięszczyk P, Krupecki K, Maciejewska A, Sawczuk M. The angiotensin converting enzyme gene I/D polymorphism in Polish rowers. *Int J Sports Med*. 2009;30:624-627.
18. Papadimitriou ID, Lucia A, Pitsiladis YP, Pushkarev VP, Dyatlov DA, Orekhov EF, Artioli GG, Guilherme JP, Lancha AH Jr, Ginevičienė V, Cięszczyk P, Maciejewska-Karłowska A, Sawczuk M, Muniesa CA, Kouvatzi A, Massidda M, Calò CM, Garton F, Houweling PJ, Wang G, Austin K, Druzhevskaya AM, Astratenkova IV, Ahmetov II, Bishop DJ, North KN, Eynon N. ACTN3 R577X and ACE I/D gene variants influence performance in elite sprinters: a multi-cohort study. *BMC Genomics*. 2016;17:285.
19. Eynon N, Hanson ED, Lucia A, Houweling PJ, Garton F, North KN, Bishop DJ. Genes for elite power and sprint performance: ACTN3 leads the way. *Sports Med*. 2013;43:803-817.
20. Yang N, MacArthur DG, Gulbin JP, Hahn AG, Beggs AH, Eastal S, North K. ACTN3 genotype is associated with human elite athletic performance. *Am J Hum Genet*. 2003;73:627-631.
21. Ruiz JR, Fernandez del Valle M, Verde Z, Diez-Vega I, Santiago C, Yvert T, Rodriguez-Romo G, Gomez-Gallego F, Molina JJ, Lucia A. ACTN3 R577X polymorphism does not influence explosive leg muscle power in elite volleyball players. *Scand J Med Sci Sports*. 2011;21:e34-e41.
22. Onisto N, Teofoli F, Zaccagni L, Gualdi-Russo E. Anthropometric traits and aging: a cross-sectional survey in diabetic elderly women. *Arch Gerontol Geriatr*. 2009;48:197-200.
23. Chmielewski P, Boryśtawski K, Chmielewicz K, Chmielewicz J. Longitudinal and cross-sectional changes with age in selected anthropometric and physiological traits in hospitalized adults: an insight from the Polish Longitudinal Study of Aging (PLSA). *Anthropological Review*. 2015;78:317-336.
24. Weiner JS, Lourie JA. *Human biology. A guide to field methods*. International Biological Programme. Oxford: Blackwell; 1969.
25. Martens R, Vealey RS, Burton D, Bump L, Smith DE. Development and validation of the Competitive Sports Anxiety Inventory-2. In: Martens R, Vealey RS, Burton D, editors. *Competitive anxiety in sport*. Champaign: Human Kinetics; 1990:127-140.
26. Jones G, Hanton S. Pre-competitive feeling states and directional anxiety interpretations. *J Sports Sci*. 2001; 19:385-95.
27. Filaire E, Alix D, Ferrand C, Verger M. Psychophysiological stress in tennis players during the first single match of a tournament. *Psychoneuroendocrino*. 2009;34:150-157.
28. Toselli S, Campa F. Anthropometry and functional movement patterns in elite male volleyball players of different competitive levels. *J Strength Cond Res*. 2017 doi.org/10.1519/JSC.0000000000002368
29. Brocherie F, Girard O, Forchino F,

- Al Haddad H, Dos Santos GA, Millet GP. Relationships between anthropometric measures and athletic performance, with special reference to repeated-sprint ability, in the Qatar national soccer team. *J Sports Sci.* 2014; 32(13):1243-54.
30. Zhao X, Tsujimoto T, Kim B, Tanaka K. Association of arch height with ankle muscle strength and physical performance in adult men. *Biol Sport.* 2017;34(2):119-126.
31. Tanaka T, Suga T, Otsuka M, Misaki J, Miyake Y, Kudo S, Nagano A, Isaka T. Relationship between the length of the forefoot bones and performance in male sprinters. *Scand J Med Sci Sports.* 2017;27(12):1673-1680.
32. Baxter JR, Novack TA, Van Werkhoven H, Pennell DR, Piazza SJ. Ankle joint mechanics and foot proportions differ between human sprinters and non-sprinters. *Proc Biol Sci.* 2012;279:2018-2024.
33. Massidda M, Corrias L, Scorcu M, Vona G, Calò CM. ACTN-3 and ACE genotypes in elite male Italian athletes. *Anthropological Review.* 2012; 75:51-59.
34. Mikami E, Fuku N, Murakami H, Tsuchie H, Takahashi H, Ohiwa N, Tanaka H, Pitsiladis YP, Higuchi M, Miyachi M, Kawahara T, Tanaka M. ACTN3 R577X Genotype is associated with sprinting in elite Japanese athletes. *Int J Sports Med.* 2014;35:172-177.