Sports Science

Effect of somatotype on the general physical fitness tests and throwing velocity on handball

Konstantinos S. Noutsos[1], Panagiotis Meletakos[1], Vasileios Manasis[2], Panagiota Papadopoulou[1], Ioannis Bayios[1]

[1]National & Kapodistrian University of Athens, School of Physical Education & Sports Science, Sector of Sports Games, Athens, Greece; [2]National & Kapodistrian University of Athens, School of Physical Education & Sports Science, Sport Economics, Athens, Greece.

Associate Editor: Eduardo Lusa Cadore, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil. E-mail: edcadore@yahoo.com.br.

Abstract - Aim: The study aimed to investigate the effects of the somatotype components on handball. **Methods:** The sample consisted of 60 elite junior handball players. Somatotype was evaluated using the Heath & Carter method. The kinetic performance trials of the handball athletes were running speed performance over 5 m 10 m and 20 m sprints, sit and reach, standing long jump (SLJ), ball velocity, and maximum aerobic power. For the data analyses, we used Pearson correlation and multiple linear regression. **Results:** The endomorphic component correlated positive with all three sprint times (5 m, 10 m και 30 m sprints) (r = 0.315, p = 0.014; r = 0.367, p = 0.004; r = 0.358, p = 0.005 respectively) while negative with SLJ (r = -0.418, p = 0.001) και maximum aerobic power (r = -0.322, p = 0.012). The mesomorphic component had a positive correlation with ball velocity (r = 0.260, p = 0.045) and negative relation with SLJ (r = -0.261, p = 0.044). The ectomorphic component exhibited a negative correlation only with ball velocity (r = -0.260, p = 0.045). The ordinary least square regression models found that endomorphy and ectomorphy were prognostic factors and predicted worse performance in all of the examined motor performance indices except ball velocity and 5 m sprint, while mesomorphy was a predictor of worse performance in SLJ. **Conclusions:** In conclusion, according to the findings of this study, somatotype components play an important role in performance-related parameters.

Keywords: somatotype, physical fitness, throwing velocity, junior handball players.

Introduction

Variables related to somatotype are determinants in handball performance[1]. Among the indicators that determine the effectiveness of handball players are sprints, agility, jumps, and ball-throwing velocities[2]. It is essential that handball athletes be able to execute fast and explosive actions[3]. The acquisition of flexibility promotes athletes' performance. Lack of muscle flexibility is one of the most commonly assumed risk factors for developing muscle injuries and sit-and-reach and hamstring extensibility could be the best choice in the handball sport to assess the flexibility[4]. Speed throwing is pivotal for top-level athletes[5] while Chelly et al.[6] refer to the explosive power of the upper limbs that highly correlates with the speed of the shot. The power of the lower limbs is a fundamental attribute of handball athletes that dictates their jumping prowess[7].

Varied motor demands are reflected in the athlete's body morphology[8]. A study by Silventoinen et al.[9] showed that somatotype and physical condition characteristics reflect, to a great extent, the same genetic basis. Athletes exhibit a specific proportion of three components, endomorphy, mesomorphy, and ectomorphy that are mediated by both genetic and environmental factors[10]. Ryan-Stewart et al.[11] report that the four somatotype categories demonstrated a small potential for misclassification (29.4-38.2%) versus detailed (13 groups) somatotype categorization (39.7-72.1%). Studies support the view that mesomorphy combined with high muscle percentage and the low-fat percentage is the ruling factor in handball[12,13]. High-performance athletes who compete in a certain sport possess somatometric characteristics that can deliver a standard as far as current performance parameters are concerned[14]. Reports support the opinion that favourable somatotype characteristics offer excellent biomechanical and metabolic efficiency in the chosen sport[10].

According to Carter and Heath[15], the somatotype explained 25% to 60% of the variance in physical fitness tests. Ectomorphy and mesomorphy have been associated with better performance during aerobic fitness training in adults[16]. In addition, the power of the lower limbs was found to correlate positively with the components of mesomorphy and ectomorphy ($p \leq 0.01$) and negatively with endomorphy[17]. In high-performance athletes, Giannopoulos et al.[18] found that the variables that determine ectomorphs and endomorphs were able to explain the variance in performance by almost 25%. In the study of Ryan-Stewart et al.[19], they found that around one-third of strength performance is predicted by the somatotype-assessed physique in physically active males. Body type assessment can be used to describe changes in physique because of physical activity[20] and to be an indicator of the chosen sport and training method[21].

In handball, some papers report on anthropometric characteristics and simultaneously provide information on kinetic performance indicators[22-26]. Cavala and Katić[22] in their study observed that high-quality female handball athletes differ from the less successful ones in kinetic performance indicators and a more pronounced mesomorphic component. In another study, Cavala et al.[23] concluded that the selection of players should not only be based on physical and psychological characteristics but on related anthropological complexes that determine performance and sporting success. The study by Ramos-Sanchez and Camina-Martin[24] presented the differences in anthropometric characteristics, body composition, and somatotype characteristics of handball players according to their competitive position. Similarly, Vila et al.[25] observed significant differences in anthropometric characteristics, throwing velocity, arm grip, and lower limb muscle strength depending on their competitive position in elite Spanish female handball athletes. The aim of the study by Vuleta et al.[26] was to analyze positional differences in anthropometric traits where significant differences were recorded in 11 morphological measures with no significant differences in longitudinal dimensions. The aforementioned studies show the relationship between morphological characteristics and motor performance depending on the level of performance and playing position in handball. Also, it is of greater importance to better understand the effect of somatotype components on the motor performance characteristics of handball players through the predictability of performance level. Therefore, the purpose of the study was to investigate the effects of somatotype components on general physical fitness tests and throwing velocity in handball.

Methods

Participants

The sample consisted of 60 elite junior handball players from Greek national team selections (M ± SD; age = 17.61 ± 1.53 years; body height = 183.77 ± 5.9 cm; body mass = 82.68 ± 9.03 kg). The athletes were individuals who exercised regularly (seven workouts/training sessions per week) with a training experience of 6.86 ± 2.03 years and were familiar with all testing procedures as part of their regular performance evaluation program. The study was conducted during the in-season period. The procedure of the study was approved by the Ethical Committee of the School of Physical Education and Sports Science of the National and Kapodistrian University of Athens.

Procedures

Testing procedures

Two sessions were held to evaluate the anthropometric characteristics and performance parameters of the participants. In the first session, anthropometric characteristics were recorded, and sit and reach, standing long jump, and ball velocity tests were performed. In the second session, participants completed the running speed performance test over 5 m 10 m, and 20 m distances, and maximum aerobic power was estimated. All tests were performed in the same closed room and participants wore appropriate sports equipment to limit possible variability in test procedures. Each subject completed all tests at the same time in the day (2:00 pm-5:00 pm), and in similar ambient conditions (temperature and relative humidity). To limit the effects of fatigue, players had to avoid strenuous training 24 h before each test day. At each visit, participants performed a 15 min warm-up that included low-intensity running and several accelerations, followed by dynamic stretching of the upper and lower limbs. Prior to the final measurements, a pilot study was conducted on 15 players (test-retest) after 15 days between the first and second measurements, in order to examine the reliability of the tests (intraclass correlation coefficient and technical error of measurement). Three members of the research team performed all the tests and an effort was made to encourage the best possible result, providing positive feedback and encouragement. The data for each athlete was recorded in special protocols that included personal data, medical history, and training age. The participants completed all the tests in the following order:

Anthropometrics

Body height was measured with a stadiometer (Seca 220, UK) to the nearest 0.1 cm and body mass was recorded using a portable scale (Seca alpha model 770, UK) to the nearest 0.1 kg. Skinfold measurements were taken using a skinfold caliper (J. Bull, USA) from five sites: biceps, triceps, subscapular, suprailiac, and calf, according to standards set by Norton et al.[27] to the nearest 0.1 mm. The mid-upper-arm circumferences (cm) were measured with the arm in both tensed and relaxed positions, while calf circumference (cm) was measured with the subject sitting on a chair. Two widths, the femur, and humerus were measured to the nearest 0.1 mm (reported in cm). All variables were measured on the right side of the body following standardized procedures[22]. Two measurements were taken from each site and the value recorded was the mean, provided that there was a difference of no greater than 5% between the two measurements; if that was the case, a third measurement was taken and the median value was used. All skinfold measurements were taken indoors at approximately the same time of day by the same investigators. The technical errors of measurement of 1.5% for the sum of six skinfolds and <1% for all other measurements[28]. Somatotype components (endomorphic - mesomorphic - ectomorphic) were calculated according to the equation recommended by Carter and Heath[15].

Sit and Reach test

The Sit and Reach test was used to assess flexibility. The subject assumes a sitting position on the floor with his hips, while his feet are in contact with a box, especially constructed and calibrated for the test (sit-and-reach box). From this position and while having one palm over the other, the subject performed forward trunk flexion by stretching his arms as far as possible in order to move the measurement scale forward, while maintaining full extension of his knees. Every trial was considered valid when the subject held the position for a minimum of 2 s. The best out of two trials was recorded and used as a flexibility score (in cm).

Standing long jump (SLJ)

We evaluated the horizontal jumping ability using SLJ. Participants were asked to stand on both legs and leap forward as far as possible and land on both legs. The distance between the toe position at the start of the jump and the heel position during landing was measured. SLJ was performed three times, and the higher of the three measurements was used for the final analysis.

Ball velocity

Ball velocity was measured using a Radar Gun (Sports Radar 3300, Sports Electronics Inc) with ±0.1 km/h accuracy within a field of 10° from the gun. The subject performed a standing throw upon instruction to throw a regular ball (440 g for maximum velocity. The Radar Gun was located 6 m from the subject and at the subject's throwing arm height. Ball velocity was recorded in km/h and calculated as the best obtained from two trials.

Running speed

The sprint 5 m, 10 m and 30 m tests were used to evaluate the maximum running speed. The subject, from an upright position 30 cm behind the first pair of photocells without any command and on his initiative started to run in order to pass the 5 m, 10 m and 30 m positions where there were two pairs of wireless timing gates. Two attempts were made with a rest period of at least ten min between them and the fastest attempt was recorded for further analysis. The time count was done with Fitlight photocells (Fitlight Sports Corp., Ontario, Canada).

Maximum aerobic power

The 20 m multistage shuttle run test is a field test that is used to assess the maximum aerobic power and to indirectly evaluate maximum oxygen uptake[29]. The test consists of a shuttle running between two lines placed 20 m apart at progressively increasing speeds. The initial running speed was set at 8.5 km/h and was increased by 0.5 km/h each minute, according to an auditory signal transmitted by a portable cd player. The test stops either when the subject voluntarily withdraws or is unable to follow the pace set by the auditory signal, i.e. failing to arrive within 2 m or more on the 20 m end line before the emission of the next auditory signal. The stage where the subject finished the test is considered an evaluation index of maximum aerobic power and is measured in $mL·kg^{-1}·min^{-1}$.

Statistical analyses

Statistical analyses were carried out using the SPSS 20 program for Windows (SPSS, Inc., Chicago, IL, United States). To show the characteristics of the participants, descriptive statistics were made for all variables (Mean ± SD). The test-retest reliability of the general physical fitness tests and throwing velocity were evaluated using intraclass correlation coefficients (ICC) and the typical error of measurement (TE). To test the normality of the sample Kolmogorov-Smirnov, Shapiro-Wilk, and Levene's tests were applied. A Pearson correlation analysis was completed to compare somatotype ratings for endomorphy, mesomorphy, and ectomorphy with a 5 m sprint, 10 m sprint, 30 m sprint, sit and reach test, standing long jump, ball velocity, and maximum aerobic power. Multiple linear regression was used with independent variables endomorphy, mesomorphy, and ectomorphy and with performance variables as dependent variables. The ordinary least square regression (OLS) has been used to identify the explanatory variables of all performance variables. Starting with the initial OLS model, which includes the three somatotype variables of interest, we followed the backward stepwise selection to determine the somatotype variables that could predict performance. In all cases, the level of statistical significance was set at $p < 0.05$.

Results

The results of the intraclass correlation coefficient for test-retest reliability and typical error of measurement values for the general physical fitness tests and throwing velocity are presented in Table 1.

The means and standard deviations of somatotype results and general physical fitness tests and throwing velocity of the participants analyzed in the current study

Table 1 - Reliability of the general physical fitness tests and throwing velocity.

Variables	ICC	%TE
Sit and Reach Test (cm)	0.97	2.1
5 m Sprint time (s)	0.82	2.4
10 m Sprint time (s)	0.82	1.6
30 m Sprint time (s)	0.91	1.0
Standing long jump (cm)	0.97	1.4
Ball velocity at standing position ($km.h^{-1}$)	0.90	3.2
Maximal aerobic power ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	0.87	3.4

ICC: intraclass correlation coefficient; TE: typical error of measurement.

were summarized in Table 2 and Table 3 shows the correlation between somatotype components and handball general physical fitness tests and throwing velocity.

The endomorphic component was found to have positive correlation with all three sprint times (5 m, 10 m and 30 m sprint) (r = 0.315, p = 0.014; r = 0.367, p = 0.004; r = 0.358, p = 0.005 respectively) as well as negatives with SLJ (r = -0.418, p = 0.001) and maximum aerobic power (r = -0.322, p = 0.012). Mesomorphy had a positive correlation with ball velocity (r = 0.260, p = 0.045) and a negative correlation with SLJ (r = -0.261, p = 0.044) while the ectomorphy component showed a negative correlation only with ball velocity (r = -0.260, p = 0.045). The sit and reach test was not correlated with somatotype variables. The linear regression models concerning the performance indices as well as the prediction equations obtained for each kinetic performance test are presented in Table 4.

The quotient F is statistically significant (p < 0.001) for all general physical fitness tests and throwing velocity except for the sit and reach test and it shows that at least one variable has a significant contribution to performance prediction. Prediction models for the performance of motor indices showed that somatotype components could explain 5% to 23% of cases. Multicollinearity was not observed in any of the regression models (VIF < 5 for all regression coefficients).

Table 2 - Somatotype values and performance measures for elite young handball players.

Variable	Mean ± SD	Minimum	Maximum
Endomorphy	2.92 ± 0.78	1.6	5.01
Mesomorphy	3.28 ± 1.15	1.0	5.8
Ectomorphy	2.36 ± 1.13	0.6	4.7
Sit and Reach Test (cm)	38.70 ± 6.64	22.0	60.0
5 m Sprint time (s)	1.05 ± 0.06	0.94	1.23
10 m Sprint time (s)	1.81 ± 0.06	1.68	1.96
30 m Sprint time (s)	4.35 ± 0.14	4.05	4.64
Standing long jump (cm)	235.58 ± 19.57	184	284
Ball velocity at standing position ($km.h^{-1}$)	84.08 ± 7.46	62.8	99.8
Maximal aerobic power ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	47.81 ± 4.32	39.9	58.5

Discussion

The main findings of the current study found a significantly low correlation between somatotype characteristics and certain general physical fitness tests and throwing velocity. During the verification process between somatotype variables and general physical fitness tests and throwing velocity, the findings of the current study concur with other published studies in handball and volleyball, where higher endomorphy corresponds to less power in the lower limbs, reduced cardiopulmonary capabilities and hence lower sprint performance[30,31]. Endomorphy is characterized by a higher percentage of body fat[19] and for the optimum performance of a handball player, the percentage of body fat must be within the recommended figures[32]. In their study, Hermassi et al.[33] witnessed that fat percentage seemed to have a negative effect on handball players not only on their aerobic capacity but also on their anaerobic capacities such as shots, sprints, and jumps. Explaining the results of our study, higher endomorphy relates to worse sprint times. Barbieri et al.[34] ascertained those sprinters with large muscle mass, lower adiposity, less ectomorphy, and more strength had better performances. According to Martínez-Rodríguez et al.[32], greater muscle mass is often an advantageous characteristic in sports, as in team handball, where speed is so much of the essence.

Table 3 - Pearson's correlation between somatotype components and general physical fitness tests and throwing velocity.

Variables	Endomorphy	Mesomorphy	Ectomorphy
Sit and Reach Test (cm)	NS	NS	NS
5 m Sprint time (s)	r = 0.315, p = 0.011	NS	NS
10 m Sprint time (s)	r = 0.367, p = 0.004	NS	NS
30 m Sprint time (s)	r = 0.358, p = 0.005	NS	NS
Standing long jump (cm)	r = -0.418, p = 0.001	r = -0.261, p = 0.044	NS
Ball velocity at standing position ($km.h^{-1}$)	NS	r = 0.260, p = 0.045	r = -0.260, p = 0.045
Maximal aerobic power ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	r = -0.322, p = 0.012	NS	NS

Table 4 - Regression results for different performance models.

Dependent Variable	R^2 Adj.	p-value	Included Independent variables	SC	p-value	Equation
Sit and Reach Test (cm)			Endo	-0.276	N/A	
	0.05	0.118	Meso	-0.586	N/A	N/A
			Ecto	-0.485	N/A	
5 m Sprint time (s)	0.08	0.014	Endo	0.459	0.014	5 m Sprint = 0.985 + 0.024 * Endo
10 m Sprint time (s)			Endo	0.367	0.001	10 m Sprint = 1.619 + 0.050 * Endo + 0.019 * Ecto
	0.17	0.002	Ecto	0.341	0.046	
30 m Sprint time (s)	0.19	0.001	Endo	0.657	0.001	30 m Sprint = 3.863 + 0.122 * Endo+0.054 * Ecto
			Ecto	0.425	0.013	
Standing long jump (cm)	0.23	0.001	Endo	-0.623	0.001	Standing long jump = 355.048 - 15.510 * Endo - 11.667 * Meso - 15.129 * Ecto
			Meso	-0.694	0.002	
			Ecto	-0.878	0.009	
Ball velocity at standing position ($km.h^{-1}$)	0.05	0.044	Ecto	-0.119	0.001	Ball velocity at standing position = 88.126 - 1.711* Ecto
Maximal aerobic power ($mL{\cdot}kg^{-1}{\cdot}min^{-1}$)	0.13	0.007	Endo	-0.556	0.060	Maximal aerobic power = 59.702 - 3.047 * Endo - 1.253 * Ecto
			Ecto	-0.361	0.002	

R2 Adj.: R2 adjusted; SC: Standardized coefficients; Endo: Endomorphy; Meso: Mesomorphy; Ecto: Ectomorphy.

Consequently, it is probable that higher endomorphy results in worse results in acceleration and body movement. In our study, endomorphy exhibited a negative correlation in the long jump which concurs with Saha et al.[17] which reported a negative correlation between the endomorphy component and leg explosive power. Busko et al.[35] in volleyball players found that there was a negative correlation between jump height and endomorphic component ($r = 0.59$). It would seem that endomorphy has a negative effect on the long jump and might act as a limiting factor in propulsion and lifting body tasks. One of the reliable parameters in measuring athletic performance and the level of training is maximum oxygen uptake. Endomorphy adversely impacts the heart during training caused by body muscles not receiving sufficient quantities of oxygen due to the deposition of high levels of fatty tissue[36]. Our study found a negative correlation between the endomorphic component and maximum aerobic power. Our results concur with those of Marangoz et al.[31] on high-performance handball players where a highly negative correlation was found between maximum aerobic power and endomorph value ($r = -0.702$, $p < 0.001$). The findings of the study Chaouaci et al.[16] show that ectomorphy contributes positively to aerobic capability. It seems that endomorphy has an adverse effect on maximum aerobic power.

Mesomorphy reflects muscle development which positively relates to power[37]. In handball, muscle power is a very important aspect of performance[38], and more muscular and powerful handball players tend to have an advantage[39]. Our results exhibited a positive correlation between the mesomorphic component and ball velocity. The study by Havolli et al.[40] on elite handball players concluded that more muscle mass in the lower and upper limbs manifests in better shooting performance and muscle power. Several studies in handball show a correlation of ($r > 0.60$) between muscle power and shot speed[39]. Consequently, increased muscle mass, a mesomorphic component, can have a beneficial effect on shot performance. Our results also showed a negative correlation between the mesomorphic component and horizontal jump capability. The optimum body composition of athletes is characterized by high levels of muscle mass[41]. However, our findings showed that mesomorphy related negatively to SLJ which means that more muscle mass negatively impacts the jump and forward body movement of handball players. These findings may probably be explained through the mesomorphic component, and refer to the development of the skeletal muscle that exhibits hypertrophy and can negatively impact jump capability.

The current study showed a negative correlation between ectomorphy and ball velocity. Ectomorphy negatively correlates with force and reflects muscular hypotonia[37,42]. Shot speed is the result of the power in the muscular groups in the upper and lower limbs[43]. On the other hand, the linearity of the body structure corresponding to ectomorphy translates to less muscle mass and in turn lower levels of attained muscular strength[37]. The predominantly ectomorphic person, having a tall and slim somatotype, can negatively influence shot performance.

There was no significant difference between flexibility performance and somatotype components ($p = 0.670$)

in our study. In the bibliography, some studies show there is no correlation between flexibility and somatotype components[14]. Flexibility is a physical capacity that could be more influenced by the adaptations produced by training, as it seems to be sensitive to the changes produced by training, improving it and producing morphological and neurological adaptations[44].

The ordinary least square regression models for elite junior handball players were set to determine the effects of somatotype on general physical fitness tests and throwing velocity. It was found that endomorphy is a prognostic factor and forecasts negative effects for the forecast models of all the examined motor indices except for ball velocity. In their study, Hermassi et al.[45] found that in adolescent handball players, the % BF predicted a significant 8 -15% portion in running performances and aerobic capacity. This might be because, for motor abilities that are characterized by muscle power and maximum oxygen uptake, the extra weight in the form of fatty tissue may affect performance thus requiring greater effort for movements[3]. In addition, ectomorphy is a prognostic factor and foresaw negative effects in the forecast models in all the examined indices except for the 5m sprint while mesomorphy is a prognostic index and foresaw a negative effect in the forecast model only for SLJ. In his study, Ryan-Stewart et al.[19] in physically active males presented a negative correlation between ectomorphy and power performance of the upper and lower parts of the body. In the multivariate analysis, the addition of mesomorphy seems to bypass the negative correlation of ectomorphy with power so that being slimmer and muscular combine to create better power performances for the lower limbs. The findings of the study of Chaouach et al.[16] showed that athletes exhibited better performances in aerobic abilities when the components of mesomorphy and ectomorphy were balanced rather than when mesomorphy was dominant. A possible explanation that can be given through multivariate analyses, is when the somatotype components are examined separately. When dominant, they had a negative effect on performance on the forecast models of the examined general physical fitness tests and throwing velocity.

The main limitation of this study is the small sample size and it is important when looking at the results although it is difficult to have a large number of subjects at the national team level. Consequently, with such a small sample size, the results reflect only this group and not the whole population. Second, the playing positions of the handball players were not taken into account in this study. Each playing position requires unique physical and motor characteristics to maximize performance and they receive different training for their playing position. Therefore, these data should be interpreted with caution when compared to similar studies.

Conclusions

In conclusion, the findings show that somatotype influences various indices of body performance. In particular, endomorphy, in all our analyses was found to have a negative effect on most of the performance indices. The evaluation of somatotype components is a fundamental aspect that should aim at determining the optimal body composition of athletes by presenting a unique combination of somatotype components related to the improvement of general physical fitness tests and throwing velocity. These results could help to improve coaches' knowledge of high-performance athletes, especially in the country where the study was conducted. In addition, this information on the effect between somatotype data and general physical fitness tests and throwing velocity can serve as a tool to guide and develop improved training programs that lead to higher levels of performance.

References

1. Saavedra JM, Halldórsson K, Þorgeirsson S, Einarsson I, GuÐmundsdóttir ML. Prediction of handball's players performance on the basis of kinanthropometric variables, conditioning abilities, and handball skills. J Hum Kinet. 2020;73:229-39. doi
2. Noutsos SK, Meletakos P, Athanasiou P, Tavlaridis A, Bayios I. Effect of plyometric training on performance parameters in young handball players. Gazz Med Ital. 2021;180 (10):568-74. doi
3. Papanikolaou F, Rousanoglou E, Psychountaki M, Noutsos K. Relationship between throwing accuracy and performance indices in female and male adolescent handball players. JPES. 2021;21(5):2633-40. doi
4. Camacho-Cardenosa A, Camacho-Cardenosa M, Brazo-Sayavera J. How assessment the flexibility in handball players? Results of a systematic review. Supplementary Issue: Proceedings of the International Seminar of Physical Education, Leisure and Health; Castelo Branco, Portugal. J Hum Sport Exerc. 2019;14(4proc):S1169-S1823. doi
5. Aloui G, Hermassi S, Hayes LD, Shephard RJ, Chelly MS, Schwesig R. Effects of elastic band plyometric training on physical performance of team handball players. Appl Sci. 2021;11(3):1309. doi
6. Chelly MS, Hermassi S, Aouadi R, Shephard RJ. Effects of 8-week in-season plyometric training on upper and lower limb performance of elite adolescent handball players. J Strength Cond Res. 2014;28(5):1401-10. doi
7. Ortega-Becerra M, Pareja-Blanco F, Jiménez-Reyes P, Cuadrado-Peñafiel V, González-Badillo JJ. Determinant factors of physical performance and specific throwing in handball players of different ages. J Strength Cond Res. 2018;32:1778-86. doi
8. Massuca L, Fragoso I. Morphological characteristics of adult male handball players considering five levels of performance and playing position. Coll Antropol. 2015;29 (1):109-18. PMID
9. Silventoinen K, Jelenkovic A, Palviainen T, Dunkel L, Kaprio J. The association between puberty timing and body mass

index in a longitudinal setting: the contribution of genetic factors. Behav Genet. 2022;52:186-94. doi
10. Wilber RL, Pitsiladis YP. Kenyan and Ethiopian distance runners: what makes them so good? Int J Sports Physiol Perform. 2012;7(2):92-102. doi
11. Ryan-Stewart H, Faulkner J, Jobson S. The impact of technical error of measurement on somatotype categorization. Appl Sci. 2022;12(6):3056. doi
12. Noutsos SK, Meletakos GP, Bayios AI. Morphological characteristics of adolescent elite female handball and volleyball players. JPES. 2019;19(Supp. 4):1502-7. doi
13. Rousanoglou E, Noutsos K, Bayios I. Playing level and playing position differences of anthropometric and physical fitness characteristics in elite junior handball players. J Sport Sci Med. 2014;54:611-21. PMID
14. Cinarli FS, Kafkas ME. The effect of somatotype characters on selected physical performance parameters. Phys Educ Stud. 2019;23(6):279-87. doi
15. Carter JEL, Heath BI. Somatotyping. Development and applications. Cambridge, Cambridge University Press; 1990.
16. Chaouachi M, Chaouachi A, Chamari K, Chtara M, Feki Y, Amri M, et al. Effects of dominant somatotype on aerobic capacity trainability. Br J Sports Med. 2005;39:954-9. doi
17. Saha S. Somatotype, body composition and explosive power of athlete and non-athlete. J Sports Med Doping Stud. 2014;4:1-4. doi
18. Giannopoulos N, Vagenas G, Noutsos K, Barzouka K, Bergeles N. Somatotype, level of competition, and performance in attack in elite male volleyball. J Hum Kinet. 2017;58:131-40. doi
19. Ryan-Stewart H, Faulkner J, Jobson S. The influence of somatotype on anaerobic performance. PLoS One. 2018;13:e0197761. doi
20. Reis VM, Machado JV, Fortes MS, Fernandes PR, Silva AJ, Dantas PS, et al. Evidence for higher heritability of somatotype compared to body mass indexin female twins. J Physiol Anthropol. 2007;26:9-14. doi
21. Gutnik B, Zuoza A, Zuozienė I, Alekrinskis A, Nash D, Scherbina S. Body physique and dominant somatotype in elite and low-profile athletes with different specializations. Medicina. 2015;51(4):247-52. doi
22. Cavala M, Katić R. Morphological, motor and situation-motor characteristics of elite female handball players according to playing performance and position. Coll Antropol. 2010;34(4):1355-61. PMID
23. Cavala M, Trninić V, Jasić D, Tomljanović M. The influence of somatotype components and personality traits on the playing position and the quality of top Croatian female cadet handball players. Coll Antropol. 2013;37(Suppl 2):93-100. PMID
24. Ramos-Sanchez F, Camina-Martin MA, Alonso-de-La-Torre SR, Redondo-del-Rio P, De Mateo-Silleras B. Body composition and somatotype in professional men's handball according to playing positions. Rev int med y ciencias. Act Fis y del Deport. 2016;18:91-102. doi
25. Vila H, Manchado C, Rodriguez N, Abraldes JA, Alcaraz PE, Ferragut C. Anthropometric profile, vertical jump, and throwing velocity in elite female handball players by playing positions. J Strength Cond Res. 2012;26(8):2146-55. doi
26. Vuleta D, Bojić-Ćaćić L, Milanović D. Positional differences in anthropometric characteristics of the Croatian U18 female field handball players. Kinesiology. 2020;521:124-33. doi
27. Norton K, Olds T, Olive S, Craig N. Anthropometry and sports performance In: Anthropometrica. Sydney: UNSW Press; 1996. p. 287-364.
28. Ulijaszek SJ, Kerr DA. Anthropometric measurement error and the assessment of nutritional status. Br J Nutr. 1999;82(3):165-77. doi
29. Ramsbottom R, Brewer J, Williams C. A progressive shuttle run test to estimate maximal oxygen uptake. Br J Sport Med. 1988;22:141-44. doi
30. Acar H, Eler N. The relationship between body composition and jumping performance of volleyball players. J Educ Train Stud. 2019;7(3):192-6. doi
31. Marangoz I, Var SM. The relationship among somatotype structures, body compositions and estimated oxygen capacities of elite male handball players. Asian J Educ Train. 2018;4(3):216-9. doi
32. Martínez-Rodríguez A, Martínez-Olcina M, Hernández-García M, Rubio-Arias JÁ, Sánchez-Sánchez J, Lara-Cobos D, et al. Mediterranean diet adherence, body composition and performance in beach handball players: a cross sectional study. J Environ Res Public Health. 2021;18:2837. doi
33. Hermassi S, van den Tillaar R, Bragazzi NL, Schwesig R. The associations between physical performance and anthropometric characteristics in obese and non-obese schoolchild handball players. Front Psychol. 2021;11:580991. doi
34. Barbieri D, Zaccagni L, Babic V, Rakovac M, Mišigoj-Duraković M, Gualdi-Russo E. Body composition and size in sprint athletes. J Sports Med Phys Fitness. 2017;57:1142-6. doi
35. Busko K, Lewandowska J, Lipinska M, Michalski R, Pastuszak A. Somatotype-variables related to muscle torque and power output in female volleyball players. Acta Bioeng Biomech. 2013;15(2):119-26. doi
36. Moss SL, McWhannell N, Michalsik LB, Twist C. Anthropometric and physical performance characteristics of top-elite, elite and non-elite youth female team handball players. J Sports Sci. 2015;33(17):1780-9. doi
37. Malina RM, Bouchard C. Growth, malnutrition, and physical activity. Champaign, Human Kinetics; 1991.
38. Manchado C, Tortosa-Martinez J, Vila H, Ferragut C., Platen P. Performance factors in women's team handball: physical and physiological aspects. A review. J Strength Cond Res. 2013;27(6):1708-19. doi
39. Gorostiaga EM, Granados C, Ibanez J, Izquierdo M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. Int J Sports Med. 2005;26(3):225-32. doi
40. Havolli J, Bahtiri A, Kambič T, Idrizović K, Bjelica D, Pori P. Anthropometric characteristics, maximal isokinetic strength and selected handball power indicators are specific to playing positions in elite Kosovan handball Players. Appl Sci. 2020;10(19):6774. doi

41. Turnagöl, HH. Body composition and bone mineral density of collegiate American football players. J Hum Kinet. 2016; 51:103. doi
42. Dumith S, Ramires V, Souza M, Moraes D, Petry F, Oliveira E, et al. Overweight/obesity and physical fitness among children and adolescents. J Phys Act Health. 2010;7:641-8. doi
43. Vila H, Ferragut C. Throwing speed in team handball: a systematic review. Int J Perform Anal Sport. 2019;19(5):724-36. doi
44. Klaver M, De Blok CJM, Wiepjes CM, Nota NM, Dekker MJHJ, De Mutsert R, et al. Changes in regional body fat, lean body mass, and body shape in trans persons using cross-sex hormonal therapy: results from a multicenter prospective study. Eur J Endocrinol. 2018;178(2):163-71. doi
45. Hermassi S, Bragazzi NL, Majed L. Body fat is a predictor of physical fitness in obese adolescent handball athletes. Int J Environ Res Public Health. 2020; 7:8428. doi

Corresponding author

Konstantinos S. Noutsos. National & Kapodistrian University of Athens, School of Physical Education & Sports Science, Sector of Sports Games, Athens, Greece.
E-mail: knutsos@phed.uoa.gr.

Manuscript received on June 2, 2022
Manuscript accepted on September 22, 2022