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Algorithms for Evaluating the Body Composition of Elite Female Handball Players: Models for Optimizing the Body Status for Goalkeepers and Field Players

Algoritmos para Evaluar la Composición Corporal de Jugadoras de Balonmano de Élite: Modelos para Optimizar el Estado Corporal de Porteras y Jugadoras de Campo

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SUMMARY: Sports training and competitive performance lead to statistically significant changes in the body composition of elite handball players. These changes are sport-specific, varying by sex, being more pronounced in women than in men, and also differs across body segments. The aim of this study was to identify the anthropomorphological characteristics that most effectively represent the body composition of top female handball players, with a focus on the two primary positions in the game: goalkeeper and field player. Furthermore, the study aimed at developing algorithms for evaluating the body composition status of international level female handball players. This was achieved by applying an innovative scientific and methodological approach aimed at optimizing the anthropomorphological status for the two playing positions. Forty-nine elite female handball players participated in the study, divided into two groups based on their playing positions: goalkepers (age = 22.7 ± 4.3 years, training experience = 11.5 ± 5.1 years) and field players (age = 23.0 ± 3.0 years, training experience = 11.3 ± 3.2 years). The results of this research indicate three significant variables in determining the anthropomorphological status and body composition of elite female handball players at the international competitive level: body height (BH), relative body fatness (PBF), and the amount of muscularity relative to body longitudinality (SMMI). The only difference between two groups lies in the influence of two variables: PBF and SMMI. Goalkeepers had a higher body fat percentage and less muscle mass, while field players exhibit the opposite: lower fat percentage and more muscle mass relative to body length.

KEY WORDS: Body Composition; Female Handball Players; Bioimpedance; Algorithms.

INTRODUCTION

Although female athletes who compete in different team sport games compete in related sports from the same sports field, differences in the size of the playing field, in the rules of the game, as well as differences in motor and technical-tactical tasks affect a completely different anthropomorphological and body composition topology of players (Mala *et al*., 2015).

Handball is an Olympic sport and belongs to the category of sports games in which controlled contact with opposing players is allowed (Manchado *et al*., 2013). In terms of intensity, it is categorized as an intermittent high-intensity sport, with changes in intensity during the game in all work zones (from minimum to maximum), while the duration of the game is 60 minutes (Michalsik *et al*., 2014). In relation to the motor structure, all types of movement are represented (linear, non-linear, lateral, acyclic, combined, etc.), during the game a large number of jumps, passes and ball receptions, accelerations, decelerations are realized, and all this with active interference by opposing players (Manchado *et al*., 2013; Weber *et al*., 2018). In other words, handball players must be physically prepared in all stress zones (anaerobic and aerobic), must be prepared for the expression of all types of contractility (maximum and specific strength and power, as well as endurance in the expression of strength and power), and have high performance in terms of agility and competitive skills (general and specific) (Hatzimanouil, 2019).

During the competitive season, under the influence of training and matches, it was found that the body composition of elite handball players changes statistically significantly, and that the structure of these changes is sport-specific, both in

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relation to gender (the changes are greater in women than in men) and body segment (there are greater changes in the cranial part than in the caudal part) (Cichy *et al*., 2020).

All these facts determine specifics in planning and programming, as well as the realization of the training process, as a long-term systematic and sport-specific exercise in order to achieve optimal competitive handball performance, in relation to which physical status is a very important component. Accordingly, the consequence of such long-term systematic programmed training influence, and in terms of achieving optimal handball performance, is the effect of specific adaptation of all body systems, such as physical, motor, cognitive, and even morphological body systems, i.e. the effect of specific positive adaptation of body composition (Manchado *et al*., 2013; Bankovic´ *et al*., 2018; Cichy *et al*., 2020; Zaric *et al*., 2020; Dopsaj *et al*., 2021; Castillo *et al*., 2022).

The main goal of this research is to define anthropomorphological characteristics in terms of determining the most representative individual variables, which represent specificity in relation to the body composition of top female handball players from the aspect of two basic positions in the game - goalkeeper and field player (Weber *et al*., 2018). The secondary goal is to define algorithms for assessing the body composition status of international level female handball players by applying an innovative scientific-methodological procedure in terms of optimizing the anthropomorphological status of female goalkeepers and field players.

MATERIAL AND METHOD

This research belongs to a cross-selection study, and by the applied measurement procedure, it belongs to the laboratory testing method.

Subject Sample. International level female handball players participated in the research (n = 49; where: 17 players from the senior national team of Slovenia, 10 players from the senior national team of Serbia, and 22 players from Serbia with an international career). In relation to the examined sample, the total sample was divided into the two basic categories of playing according to criterion variable of research: 9 female goalkeepers (age = 22.7 ± 4.3 years, training experience = 11.5 ± 5.1 years), and 40 female field players (age = 23.0 ± 3.0 years, training experience = 11.3 ± 3.2 years). The study was approved by the Ethics Commission of the Faculty of Sport and Physical Education, University of Belgrade (Number 484-2).

Measurement of Body Composition. The measurement of body composition was carried out in accordance with the standardized procedure published earlier (Bankovic *et al*., 2018; Dopsaj *et al*., 2020) and was done in the morning hours (08:00 - 10:00) in the period from 2018 to 2020. The measurements were carried out in parallel at two University laboratories: Faculty of Sport University of Ljubljana, Slovenia, and Faculty of Sport and Physical Education University of Belgrade, Serbia, using the same measurement technology with the InBody720 multisegmental bioelectrical impedance device (InBody 720: Biospace Co. Ltd, Seoul, Republic of Korea).

Variables. The variables used in this research were selected based on data from previously published literature with research on the body composition of athletes, tactical athletes or healthy, physically active population (Dopsaj *et al*., 2017; Bankovic *et al*., 2018; Zaric *et al*., 2020; Dopsaj *et al*., 2020; Dopsaj *et al*., 2023; Toskic *et al*., 2024; Richa *et al*., 2024). Selected variables represent a synthesis of knowledge from the given research field. The variables represented, in addition to the basic measures of body structure (BH, BM, BF, SMM and TBW), all derived variables defined in relation to body longitudinality (BMI, FMI and SMMI), body voluminosity (PBF and PSMM), as well as index variables represented by their relations (PFI and IBC), as well:

1. BH, body height, as a measure of basic body longitudinality variable, expressed in cm;
2. BM, body mass, as a measure of basic body voluminosity variable, expressed in kg;
3. FM, body fat mass, as a total amount of fat (ballast) tissue mass in the body variable, expressed in kg;
4. SMM, skeletal muscle mass, as a total amount of skeletal muscles (contractile) tissue mass in the body variable, expressed in kg;
5. TBW, total body water, as a total amount of water (fluid) in the body variable, expressed in L;
6. BMI, body mass index, as a measure of total body mass independent of (as a function of) longitudinality, calculated as: BM/BH2 (m), expressed in $kg·m^{-2}$;
7. FMI, fat mass index, as a measure of total body fat mass independent of longitudinality variable, calculated as: FM/BH^2 (m), expressed in $kg·m^{-2}$;
8. SMMI, skeletal muscle mass index, as a measure of the total muscle mass of the body independent of longitudinality variable, calculated as: SMM/BH2 (m), expressed in $kg·m^{-2}$;
9. PBF, percentage of body fat, as a measure of body fat mass independent of (as a function of) voluminosity variable, calculated as: BF/BM, expressed in %;
10. PSMM, percentage of skeletal muscle mass, as a measure of skeletal muscle mass independent of voluminosity variable, calculated as: SMM/BM, expressed in %;
11. PFI, protein-fat index, calculated as relation between proteins (in kg) and body fat mass (in kg) variable,

expressed in kg;

12. IBC, index of body composition, calculated as relation between BMI (in kg·m^{-2}) and percent of body fat mass (in kg) variable, expressed in Index Unit (IU).

Statistics. All raw data were analyzed by descriptive statistical procedures to calculate: MEAN - as a basic measure of central tendency, SD - as a dispersion of data, cV% - coefficient of variation as a data homogeneity measure, and upper and lower 95 % confidence intervals of the mean. The multivariate and univariate analysis of variance (MANOVA and ANOVA) was used to calculate differences between analyzed body composition variables according to subsamples (goalkeepers and field players). Principal Component Analysis (Factor analysis, confirmatory type) with Varimax rotation and Kaiser normalization was used to reduce the set of used variables into sport-specific body composition factor. The mentioned analysis was done for each examined subsample (position) separately. The first extracted variable in the extracted factors represented the methodologically most important variable for the sports-sensitive and position-sensitive specification of body composition. Finally, from all extracted factors with the first factor variables, the standardized score was defined, which represented generalized multifactor information expressed as a score about the body composition of each subject from the subsamples (Body Composition Score, BC_Score). Multivariate regression analysis (MRA) was used to define the algorithm model for estimating the optimal body composition of female handball players, which was done in accordance with previously published research (Dopsaj *et al*., 2021). The level of statistical significance was defined based on criterion $p < 0.05$ (Hair *et al*., 1998). All statistical analyses were conducted using the IBM SPSS 25 (IBM Corp., 2017) and Microsoft Excel (Microsoft Corp., 2018) statistical software.

RESULTS

Table I shows all descriptive data for explored variables with general and partial differences between groups and variables.

No general statistically significant difference was found between the analyzed groups (MANOVA, Wilks' Lambda Value = 0.654, F = 1.590, p = 0.139, Partial Eta^2 = 0.346, Observed Power = 0.710). However, a statistically significant difference was found between the following pairs of variables: SMMI, F = 7.108, p = 0.010, Partial Eta^2 = 0.131, Observed Power = 0.743, and PSMM, F = 4.099, p = 0.049, Partial Eta^2 = 0.080, Observed Power = 0.509 (Table I).

Table II shows results of extracted body composition total variance pattern with factor structure of Rotated Component Matrix according to subsamples.

Table III shows the results of multiple regression analysis in relation to subsamples with parameters of strength and precision of defined models of body composition estimation algorithms of international female handball players.

ANOVA of Multiple Linear Regression (Table III) showed that the defined algorithms of the model are very accurate (100 % explanation of the variance of the predictive space), and that they have a very low level of estimation error (0.003 and 0.002 points).

Table I. Descriptive data with differences between observed groups and variables.

	Goalkeepers (N = 9)				Field players (N=40)			
	Mean ± SD	cV%	95 % Conf. Int. Mean		Mean ± SD	cV%	95 % Conf. Int. Mean	
			Lower	Upper			Lower	Upper
BH	175.6±5.6	3.2	171.3	179.9	174.5±6.0	3.4	172.6	174.0
BM	70.7±10.9	15.4	62.3	79.2	69.7±7.3	10.5	67.4	72.0
BF	17.5±9.0	51.4	10.5	24.4	14.1±4.0	28.4	12.8	15.4
SMM	29.7±2.4	8.1	27.8	31.5	31.2±3.3	10.6	30.2	32.3
TBW	39.8±4.3	10.8	36.5	43.1	40.67±3.96	9.7	39.40	41.93
BMI	22.90±2.96	12.9	22.61	22.54	22.86±1.73	7.6	22.31	23.41
FMI	5.63±2.80	49.7	3.49	7.78	4.64±1.33	28.7	4.21	5.06
SMMI **	9.66±0.51	5.3	9.24	10.01	10.23±0.63	6.2	10.03	10.43
PBF	23.75±7.96	33.5	17.64	29.87	20.06±4.69	23.4	18.56	21.56
PSMM *	42.50±4.49	10.6	39.05	45.96	44.89±2.85	6.3	43.98	45.80
PFI	0.701±0.238	33.9	0.518	0.884	0.860±0.347	40.3	0.749	0.971
IBC	1.015±0.191	18.8	0.868	1.018	1.202±0.312	26.0	1.102	1.302

* = p < 0.05; ** = p < 0.01; ANOVA results: BH, p value = 0.631, Part Eta^2 = 0.005; BM, p value = 0.726, Part Eta^2 = 0.003; BF, p value = 0.086, Part Eta^2 = 0.061; SMM, p value = 0.187, Part Eta^2 = 0.037; TBW, p value = 0.557, Part Eta^2 = 0.007; BMI, p value = 0.956, Part Eta^2 = 0.000; FMI, p value = 0.113, Part Eta^2 = 0.053; SMMI, p value = 0.010, Part Eta^2 = 0.131; PBF, p value = 0.069, Part Eta^2 = 0.069; PSMM, p value = 0.049, Part Eta^2 = 0.080; PFI, p value = 0.200, Part Eta^2 = 0.035; IBC, p value = 0.092, Part Eta^2 = 0.059.

Table II. Results of factor structure of Rotated Component Matrix of explored variables according to subsamples.

Subsamples	Goalkeepers			Field Players		
	Initial Eigenvalues			Initial Eigenvalues		
	Components			Components		
Total	8.21	2.35	1.14	6.28	4.28	1.09
% of Variance	68.38	19.56	9.52	52.34	37.09	7.65
Cumulative %	68.38	87.94	97.46	52.34	89.43	97.08
Variables	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
PBF	.991			.986		
PSMM	-.989			-.975		
FMI	.981			.965		
BF	.968			.943		
PFI	-.961			-.938		
BMI	.924			.700		
IBC	-.900			-.915		
BM	.828				.797	
BH		.978			.983	
SMM		.856			.880	
TBW		.670			.890	
SMMI			.981			.886

Table III. Results of multiple regression analysis of power and accuracy parameters of defined models of body composition estimation algorithms of examined subsamples of female handball players.

	Multiple Linear Regression – Model summary				
Goal-keepers	R^2	Adj. R^2	Std. Error of the Estimate	ANOVA or Regression	
				F relation	p value
	1.000	1.000	0.003	114167.2	0.000
	BC_Score = –223.6983 + (PBF • 1.2729) + (BH • 1.8249) – (SMMI • 7.9914)				
Field Players	R^2	Adj. R^2	Std. Error of the Estimate	ANOVA or Regression	
				F relation	F relation
	1.000	1.000	0.002	5311021.3	0.000
	BC_Score = –301.959 – (PBF •1.4634) + (BH • 1.4356) + (SMMI • 12.7833)				

DISCUSSION

In relation to the basic measures of body longitudinality (BH), voluminosity (BM), and body nutritional status (BMI), the results of the examined sample absolutely agree with the previously published values of elite handball players from the Czech Republic and Poland (176.6 and 176.3 cm; 72.5 and 70.6 kg; 22.6 and 23.4 kg/m^2, respectively (Mala *et al*., 2015; Cichy *et al*., 2020), as well as in relation to other countries in Europe, Asia and South America (Manchado *et al*., 2013). In this way, the external validity of current data at the general anthropomorphological level was confirmed.

It was determined that the body composition between goalkeepers and field players in the current sample of international handball players does not differ at the general level (MANOVA, Wilks' Lambda Value = 0.654, p = 0.139, Partial Eta2 = 0.346). However, at the partial level, it was determined that there are two variables that are statistically significantly different, namely: SMMI (p = 0.010, Partial Eta^2 = 0.131) and PSMM (p = 0.049, Partial Eta^2 = 0.080). Based on the results, it can be concluded that goalkeepers and field players do not differ in relation to the basic longitudinality (BH) and voluminosity (BM), they do not differ in relation to the content and structure of the fat component in the body (BF, FMI, PBF), they do not differ in relation to the body water content (TBW), but they differ in relation to the body component that is morphologically responsible for the quality of movement as a morphological potential for motor skills (Kukic *et al*., 2018, 2020), which is the muscle component. It must be emphasized that the absolute value of pure muscle mass in the body (SMM) is not a factor differentiating the examined positions, but the structural distribution, first in relation to longitudinality (SMMI), and then in relation to voluminosity (PSMM) is a statistically significant factor of difference with influence on the total explained variance of differences of 13.1 and 8.0 %, respectively (Table I).

In other words, a larger mass of skeletal muscles distributed along the length of the body, i.e. body height, as well as a greater mass of skeletal muscles in relation to the total body mass, is a component that statistically significantly differentiates female field players and goalkeepers in international (elite) level handball players in favor of field players (SMMI = 10.23 vs 9.66 kg/m^2; PSMM = 44.89 vs 42.50 %, respectively, Table I). It was established earlier that SMMI is positively related to the contractile potential of muscles to achieve rapid movements, i.e. for a higher maximum level of explosiveness (RFD_{max} - maximal rate of force development), while PSMM is associated with greater capacities and level of power, agility, and specific short endurance, especially in sports games or with tactical athletes specific motoric task (Manchado *et al*., 2013 ; Zaric *et al*., 2020; Dopsaj *et al*., 2020; Dopsaj *et al*., 2024).

The results showed that the very similar structure and set of body composition variables were extracted for both goalkeepers and field players, with a highly explained cumulative variance of the extracted factors of over 97 % of the total variance (Table II).

The only essential difference established between the prediction of the optimal body composition status of field players and goalkeepers, is in the influence of the selected variables in relation to the defined algorithms, i.e. equation models for optimizing the physical status of given female players (Table III, BC_Score). Namely, the directions of influence of the variables PBF and SMMI are different, while they are the same for the variable BH (Table III). This means that it is desirable for female field players, regardless of the examined position, to be taller, while for female goalkeepers it is desirable to have a higher level of body fat percentage (PBF), with a consequently lower level of skeletal muscle per body length measurement (SMMI). For female players, it is desirable to have a lower level of body fat percentage with a consequently higher level of skeletal muscles per length of the body (Table III, BC_Score Goalkeepers, BC_Score Field Players).

It is most likely that the selection process of female players, as well as specific training adaptations in relation to the technical-tactical requirements of the game, is the main reason for the established differences between goalkeepers and field players.

The goalkeeper in handball plays a multiple role in both phases of play - defense and attack. In defense, the goalkeeper is the last player, while in attack she is the first player to begin the rapid transition of the ball from defense to attack. Therefore, the goalkeeper plays an important role in the system of protection (defense) of the team, but also in the system of starting an attack or counterattack (Weber *et al*., 2018). In relation to technical-tactical tasks the goalkeeper is the most different from her teammates because her performance often determines the development of the game as well as the final result. The goalkeeper protects the area of the goal and her task is to neutralize balls thrown by the opponent towards the goal by positioning her body in time or by moving her arms or legs (Hatzimanouil, 2019). Of course, taller and bigger individuals cover a wider area of the goal they need to guard. Also, although very hypothetical, the lower percentage of muscles found in female goalkeepers may indicate a potential beneficial characteristic that the specific cognition of anticipating the realization of a shot on goal by the opposing players is a more dominant feature for high defensive efficiency and ability for good body positioning during defense while physical ability is dominantly associated with realizing very fast movements.

In relation to the competitive activity of the field players, a total distance of 4002 ± 551 m was covered per match with a total effective playing time of 50:42 ± 5:50 m. On average, female field players made 663.8 ± 99.7 activity changes per match, with an average speed of 5.31 ± 0.33 km$^{.h-1}$, while high-intensity running accounted for 0.8 ± 0.5 % of total effective playing time per match (2.5 ± 1.8 % of total distance covered in the match). In relation to aerobic loads, the average relative load during the match was 79.4 ± 6.4 % of VO_2 max (Michalsik *et al*., 2014). The process of sport-specific selection, as well as the type of competitive and consequently training load, and the type of motor activity that consists of a large number of sprints, changes in the direction of movement, different types of jumps, obviously influenced the adaptation of the body structure of field players towards the type of above-average tall female person (compared to the general population female person) and with a lower percentage of fat in the body and a larger amount of muscle in function of longitudinality (Dopsaj *et al*., 2023). The results clearly show that the key advantage of female handball field players, in terms of body composition adaptation, lies in their ability to move more quickly and efficiently, utilizing energy more effectively during the game.

CONCLUSION

The results of this research showed that the following three variables are significant in defining the anthropomorphological status and body composition of female handball players at the international competitive level – basic body longitudinality (BH), measure of relative body fatness (PBF) and amount of muscularity per body longitudinality (SMMI). The only difference compared to the defined algorithms (model equations) for optimizing body composition between goalkeepers and field players, is in the direction of the influence of two variables - PBF and SMMI, where goalkeepers have a higher percentage of fat and less muscle mass, and field players have the opposite - a lower percentage of fat and more muscle mass in relation to the length of the body. These results can serve as an important methodological tool in the development of procedures, methods and guidelines that optimize multi-year training periods, as well as in-season training programs for international level female handball players considering body composition profile optimization.

DOPSAJ, M.; PETRONIJEVIC, M. & BON, M. Algoritmos para evaluar la composición corporal de jugadoras de balonmano de élite: Modelos para optimizar el estado corporal de porteras y jugadoras de campo. *Int. J. Morphol., 43(4)*:1173-1178, 2025.

RESUMEN: El entrenamiento deportivo y el rendimiento competitivo producen cambios estadísticamente significativos en la composición corporal de las jugadoras de balonmano de élite. Estos cambios son específicos de cada deporte, varían según el sexo, son más pronunciados en mujeres que en hombres y difieren entre segmentos corporales. El objetivo de este estudio fue identificar las características antropomorfológicas que mejor representan la composición corporal de las jugadoras de balonmano de élite, centrándose en las dos posiciones principales: portera y jugadora de campo. Además, el estudio buscó desarrollar algoritmos para evaluar el estado de la composición corporal de jugadoras de balonmano de nivel internacional. Esto se logró mediante la aplicación de un enfoque científico y metodológico innovador para optimizar el estado antropomorfológico en ambas posiciones de juego. Cuarenta y nueve jugadoras de balonmano de élite participaron en el estudio, divididas en dos grupos según sus posiciones de juego: porteras (edad = 22,7 ± 4,3 años, experiencia de entrenamiento = 11,5 ± 5,1 años) y jugadoras de campo (edad = 23,0 ± 3,0 años, experiencia de entrenamiento = 11,3 ± 3,2 años). Los resultados de esta investigación indican tres variables significativas en la determinación del estado antropomorfológico y la composición corporal de las jugadoras de balonmano de élite a nivel competitivo internacional: altura corporal (AE), grasa corporal relativa (ACR) y cantidad de muscularidad en relación con la longitudinalidad corporal (CML). La única diferencia entre los dos grupos radica en la influencia de dos variables: ACR y CML. Las porteras presentaron un mayor porcentaje de grasa corporal y menor masa muscular, mientras que las jugadoras de campo mostraron lo contrario: menor porcentaje de grasa y mayor masa muscular en relación con la longitud corporal.

PALABRAS CLAVE: Composición Corporal; Jugadoras de Balonmano; Bioimpedancia; Algoritmos.

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