

# Anthropometric and strength profiles of professional handball players in relation to their playing position – multivariate analysis

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*Purpose:* In team sports, the varied levels of physical demand associated with different field positions are reflected in the morpho-functional features of the players. The aim of this work was to recognize how the playing position in the team depends on the anthropometric profiles and the strength level of professional handball players. *Methods:* A body mass, stature, lower and upper extremity length, circumferences and skinfolds were measured in the male professional athletes. The body composition was analysed using a bioelectrical impedance method. Additionally, hand grip and back strength were measured. A statistical analysis was carried out using routinely statistical methods and principal component analysis. *Results:* Pivot players usually have the most athletic figure in terms of size and weight and relatively short legs. The backs are characterized by the android body type and low subcutaneous fat content, and a large mass of body cells. The backs and pivots have the same strength of back and hand grip. Goalkeepers have relatively long upper and lower limbs and high back and hand grip strength. The wingers are usually slender, have medium length limbs, low body fat percentage, significant extracellular mass and the lowest muscle strength. *Conclusions:* The results of the multivariate analysis were a notable and valuable addition to the study of morphological and strength differences in a group quite homogeneous like a handball team. The principal component analysis allowed for a reduction of the multidimensional structure to three variables describing body massiveness, strength, and the length and height aspect of the body.

*Key words:* body composition, strength, multivariate analysis, anthropometry, playing position

## 1. Introduction

Handball is a dynamic sport characterised by intensive, intermittent physical exertion which encourages comprehensive development among players. Success in this discipline depends not only on the players' physical fitness, but also on their mental capacities, such as the ability to analyse and assess the situation on the court, reaction time and strategic thinking. As with any team sport, the end result relies heavily on the psychophysical involvement of the players, as well as their ability to cooperate [30].

Handball players are characterised by considerable physical strength and speed, features which prove invaluable when it comes to performance. As such, strength training plays an important role among handball players, seeing that it not only increases their fitness, but also reduces the risk of injury. Additionally, proper endurance training is crucial, since players have to maintain the same pace throughout the duration of the match [25].

As stated earlier, handball matches are characterised by periods of relatively stable pace interspersed with frequent bursts of intensive physical activity associated with changes in the speed and

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direction of movement. Recent research has shown that this particular aspect of the game may be the key to achieving high success rates [18]. An analysis of the activity pattern of the players showed marked differences between individual playing positions. High-intensity locomotor activity was much greater in wingers than either backs or pivot players [2]. Backs were found to carry out the largest number of throws, while pivot players exhibited increased agility. Goalkeepers, on the other hand, were shown to possess high explosive strength. The varied physical demands in handball are reflected in the players' anthropometry, which, in turn, correlates strongly with playing positions [19]. The morphological optimisation found in team sports players has been the subject of several studies.

Research into the diversity of anthropometric and functional features in sports teams representing different competitive levels has shown a distinct somatic specification in handball teams at a high competitive level [5]. Elite players differed morphologically from the rest: they tended to be larger in stature, with higher, lean mass and larger hands dimensions. Similar tendencies were also observed regarding particular playing positions in the team [5], [20]. Body composition analysis in accordance with W.H. Sheldon's typology showed that mesomorphy dominated in the somatotype of handball players, while the physique of goalkeepers and pivot players leaned more towards endomorphy. Out of all the anthropometric variables, body composition exhibited the highest plasticity and sensitivity to training routines, which was reflected in its correlation with functional features which determine endurance and fitness levels among sportsmen [1]. The employment of new measurement techniques allowed for body composition to be assessed with varying accuracy and enabled an individual study of particular segments of the body [28]. Studies involving professional indoor team sports players (futsal, basketball and handball) point towards a link between these disciplines and body composition [26]. Futsal players were found to have heavier torsos and upper and lower extremities. Players across all three disciplines displayed muscular asymmetry resulting from extremity dominance and the employment of techniques specific to their discipline. In basketball players, the right upper and lower extremities tended to be heavier. In handball, left-handed players had heavier right lower limbs, while the opposite was true for right-handed players. Futsal players had the heaviest lower extremities owing to frequent sprints, quick changes in the direction of

movement and constant leg work involved in passing the ball [26]. Other studies have suggested a negative correlation between body adiposity and the motor skills of handball players [3]. Body composition fluctuates during handball season [8]. Studies involving an elite male Spanish handball team have shown a substantial increase in the body mass of a lean individual, which corresponded to an increase in maximum bench press strength and handball throwing velocity.

Recent years have seen a rising interest in creating a reference physical fitness profile for each playing position. Defining properly morpho-functional profiles in sports plays an important role in the training of professional teams and constitutes the key to unearthing talents efficiently and effectively [24], [27]. In elite teams, the players' body composition and morphological features are closely monitored in order to draw comparisons between different playing positions [26].

Additionally, anthropometric variables are analysed in the light of the specific demands associated with particular positions in the team [19]. Results indicate that height and body mass constitute major determinants of an individual player's performance [6]. Novice players show directly proportional strong links between throwing performance and body mass, fat free mass, arm span and hand dimensions [33]. On the other hand, the high lean mass and reduced body adiposity characteristic for elite players corresponded to increased maximum strength and muscle power, which, in turn, resulted in a higher handball throwing velocity [33]. Several other studies have shown significant variations in body fat percentage and height between individual player positions, but none of them evaluated the differences in physical features and fitness level. Step-wise multiple regression analysis has, however, revealed that single leg horizontal jumping distance could constitute a specific standardised test for predicting sprinting ability in elite handball players [9].

The aim of this paper is to recognize how the playing position in the team depends on the anthropometric profiles and the strength level of professional handball players. The study employs advanced statistical methods which enable the demonstration of important correlations between aspects of the players' morphology and their function in the team. The results of this study could help coaches select players and design training program which takes the specific needs associated with different playing positions into account, thus contributing to better performance and increase athletes success.

## 2. Materials and methods

### *Participants*

Research involved 32 Polish professional handball players aged  $28.3 \pm 6.3$  years, each with  $16.8 \pm 6.6$  years of experience. The group consisted of five goalkeepers [G] (age: 29.4; experience:  $19.0 \pm 6.4$ ), six pivot players [P] (age: 24.2; experience:  $12.2 \pm 6.0$ ), 14 backs [B] (age: 31.0; experience:  $19.5 \pm 6.4$ ) and seven wingers [W] (age: 25.5; experience:  $14.0 \pm 4.9$ ). The age and experience did not vary significantly between players in different positions. Goalkeepers and backs had the most years of experience, while pivot players had the fewest. The study was carried out towards the end of the preparatory period, before the start of the season.

The study was approved by the Ethics Committee of the University School of Physical Education in Wrocław, Poland, and conducted in accordance with the requirements of the Declaration of Helsinki. Written informed consent was obtained from all participants.

### *Measures and calculations*

All anthropometric measurements were carried out by qualified biological anthropologists who authored this paper, and involved anthropological instruments such as: anthropometer (GPM Siber Hegner Maschinen AG, Switzerland), skinfold caliper (GPM Siber Hegner Maschinen AG, Switzerland), steel tape (GPM Siber Hegner Maschinen AG, Switzerland), scale (Fawag, Poland).

The measurements were always performed one day in the morning hours. The anthropometric data presented in this paper are in accordance with international standards [22]. Each anthropometrist took the same measurements and was assisted by a recorder. All measurements other than those in the midsagittal plane were obtained from the right side of the body.

The following somatic features were measured: body mass [kg], body height [cm], leg length (up to trochanterion point) [cm], arm length (from the acromiale to the dactylion point) [cm], chest girth [cm], hip girth [cm], relaxed arm girth [cm], forearm girth [cm], thigh girth below the gluteal fold [cm], calf girth [cm], subscapular skinfold [mm], supraspinale skinfold [mm], abdominal skinfold [mm], triceps skinfold [mm], forearm skinfold [mm], thigh skinfold [mm], medial calf skinfold [mm]. Some of these features were used to calculate anthropological ratios:

BMI [body mass/body height<sup>2</sup>], leg-to-stature ratio [leg length/body height], arm-to-stature ratio [arm length/body height], chest-to-hip ratio [chest girth/hip girth] and trunk-to-limb fat ratio [ $\Sigma$  skinfolds (subscapular + supraspinale + abdominal)/ $\Sigma$  skinfolds (triceps + forearm + thigh + calf)].

Body composition was measured using the non-invasive tetrapolar version of bioelectrical impedance (BIA) method: hand-to-foot electrodes (BIA 101 analyser, Akern, Italy, software Bodygram 1.31). The principles determining the correctness of the results were taken into account when making the measurements. The following variables were included in the analysis: fat mass (FM) [kg, %], body cell mass (BCM) [kg, %] and extracellular mass (ECM) [kg, %].

The bioelectrical impedance analysis has advantages similar to the anthropometry, because it is convenient for the patient, easy to use, cost effective, safe and it is a potential field and clinical method for evaluating skeletal muscle mass and fat. BIA has been used in the large scale studies of body composition and assessment of body fluid status. The electrical impedance is measured by introducing a low-voltage and high frequency alternating current through the body. The high values of reactance and phase angle suggest intact cell membrane structures and high body cell mass. The reactance is a sensitive discriminator between subjects with normal water distribution and those with different disorders. Moreover, an assessment of reactance provides a non-invasive method of differentiating intracellular or extracellular mass in athletes.

Hand grip strength was measured using the hand grip dynamometer (T.K.K.5001, Takei Scientific Inst. Co., Ltd., Japan). The aim of this test was to measure the maximum isometric strength of the muscles in the hand and forearm. During the test, the upper limb was straight and pointing downwards [23]. Back strength was measured using the back and leg dynamometer (T.K.K.5402, Takei Scientific Inst. Co., Ltd., Japan). The subject was asked to stand straight on the dynamometer base, so that the bar was level with the knee-cap [21]. For both tests, each volunteer performed three trials with 30 seconds of rest in between. The highest score was recorded in kilograms as the reference hand grip and back leg strength.

### *Statistical analysis*

The data was processed using the Statistica 13 software package (Statsoft, USA). Levene's test was employed in order to analyse the equality of variance. The differences between groups were assessed using the analysis of variance (ANOVA) and post-hoc with

Tukey's Honest Significant Difference for unequal samples. Alpha level was set at  $p < 0.05$ . Principal component (PC) analysis was additionally performed to determine which variables explained the largest possible variance of the data set. A Box-Cox transformation was applied and the optimum number of items was established using the Kaiser normalization [14].

### 3. Results

The average height and body mass of the players equalled  $187.3 \pm 7.1$  cm and  $93.8 \pm 11.5$  kg, respectively. The average BMI was calculated at  $26.7 \pm 2.3$ . ANOVA showed that body mass and height exhibited significant statistical intergroup variance (Table 1).

Table 1. Descriptive characteristics of the participants (M – mean, SD – standard deviation,  $p$  – significance)

Group	G	W	B	P	
Variable	M (SD)	M (SD)	M (SD)	M (SD)	$p$
Anthropometry					
Body mass [kg]	98.2(14.2) <sup>a</sup>	81.9(7.2) <sup>b</sup>	93.7(6.8)	104.5(10.9)	0.001
Body height [cm]	187.6(5.9)	181.1(4.7) <sup>b</sup>	187.7(6.1)	193.4(7.8)	0.013
Leg length [cm]	100.7(3.6)	95.9(4.4)	100.7(3.8)	102.4(4.7)	0.101
Arm length [cm]	85.1(3.3)	79.6(3.6)	83.1(3.5)	84.7(5.3)	0.072
Chest girth [cm]	108.5(6.1) <sup>a</sup>	100.2(4.6) <sup>bc</sup>	107.2(4.2)	110.6(3.8)	0.002
Hip girth [cm]	109.2(5.4) <sup>a</sup>	100.4(4.4) <sup>bc</sup>	105.7(4.3)	110.6(4.9)	0.002
Arm girth [cm]	34.5(2.3)	31.9(1.3) <sup>b</sup>	34.6(1.7)	35.4(2.9)	0.015
Forearm girth [cm]	30.1(1.2)	28.3(1.1) <sup>b</sup>	29.8(1.0)	30.9(1.6)	0.004
Thigh girth [cm]	65.8(4.2) <sup>a</sup>	58.8(2.1) <sup>b</sup>	62.7(3.3)	67.0(2.9)	0.000
Calf girth [cm]	40.5(4.2)	39.3(1.7) <sup>b</sup>	40.8(2.1)	43.5(1.3)	0.025
Subscapular skinfold [mm]	9.1(2.6)	10.6(2.6)	10.4(2.9)	12.6(1.8)	0.175
Supraspinale skinfold [mm]	10.6(3.9)	11.1(3.6)	10.9(4.1)	15.4(6.6)	0.203
Abdominal skinfold [mm]	9.5(4.5)	8.8(3.3)	11.1(3.4)	14.6(7.6)	0.150
Triceps skinfold [mm]	3.7(0.5)	3.7(0.5)	4.0(1.3)	4.4(0.7)	0.579
Forearm skinfold [mm]	3.0(0.1)	3.2(0.5)	2.8(0.4) <sup>b</sup>	3.9(1.1)	0.004
Thigh skinfold [mm]	7.6(1.5)	7.1(1.8)	7.8(2.3)	9.1(2.5)	0.396
Medial calf skinfold [mm]	4.5(0.9)	4.2(1.1)	4.6(1.3)	5.4(1.5)	0.396
Anthropometric ratios					
BMI [kg/m <sup>2</sup> ]	27.8(3.0)	24.9(1.7)	26.6(2.2)	27.9(1.5)	0.070
Leg-to-stature	53.7(0.7)	52.9(1.6)	53.6(0.7)	52.7(1.9)	0.441
Arm-to-stature	45.4(1.8)	43.9(1.0)	44.2(1.1)	43.8(1.3)	0.178
Chest-to-hip ratio	99.3(1.9)	99.9(4.4)	101.5(3.8)	100.1(2.6)	0.586
Trunk-to-limb fat	157.5(57.0)	166.4(35.0)	170.5(42.6)	185.0(40.8)	0.758
Body components					
Fat mass [kg]	16.9(5.9)	13.5(4.5)	15.8(4.9)	17.3(3.6)	0.497
Body cell mass [kg]	48.8(7.3) <sup>a</sup>	39.3(4.5) <sup>b</sup>	46.6(3.6)	53.2(7.7)	0.001
Extracellular mass [kg]	32.4(4.1)	29.1(4.4)	31.3(3.3)	34.6(5.1)	0.116
Fat mass [%]	17.1(4.5)	16.5(4.9)	16.7(4.5)	16.7(3.8)	0.996
Body cell mass [%]	49.8(3.0)	48.1(5.0)	49.9(3.4)	50.8(3.1)	0.639
Extracellular mass [%]	33.1(2.2)	35.4(3.6)	33.4(3.2)	33.0(2.6)	0.448
Strength tests					
Hand grip strength [kg]	121.4(4.9) <sup>a</sup>	103.6(12.5)	117.2(14.9)	118.2(14.8)	0.048
Back strength [kg]	179.3(14.6) <sup>a</sup>	134.1(24.4)	157.1(24.9)	157.3(21.3)	0.020

<sup>a</sup> significantly different from the wing group ( $p < 0.05$ ), <sup>b</sup> significantly different from the pivot group ( $p < 0.05$ ), <sup>c</sup> significantly different from the back group ( $p < 0.05$ ).

Legend: G – goalkeepers, P – pivot players, B – backs, W – wingers.

All upper and lower extremity circumferences under study were also shown to vary considerably between playing positions. The only skinfold whose thickness varied significantly between the players was the one on the forearm.

The post hoc-test showed that the somatic features under study were the most prominent among pivot players. Their body mass was the highest by a large margin, followed by that of goalkeepers and backs. Wingers were the lightest players on the team. Pivot players were also much taller than wingers. The diversification of upper and lower limb length was not found to be statistically significant. The upper extremities were longer in goalkeepers, while slightly elongated lower limbs were observed in pivot players.

The chest and hip girth of wingers was markedly smaller in comparison with the rest of the players. Arm, forearm, thigh and lower leg circumferences were the largest among pivot players and smallest among wingers. With the exception of thigh girth, all of the aforementioned features were similar in both goalkeepers and backs.

Skinfold thickness did not vary significantly between the groups. The thickest folds were found in pivot players, while goalkeepers tended to have the lowest levels of body fat under the shoulder blade and above the iliac crest. Abdominal, triceps, thigh and medial calf skinfolds were the smallest among wingers. The only variable whose intergroup diversity proved statistically significant was subcutaneous fat in the forearm, with the lowest levels recorded among backs.

The BMI of wingers was the lowest out of all the players and did not exceed 25.0. Pivot players and goalkeepers were found to have the highest BMI. Wingers and pivot players were shown to have the shortest lower limbs in relation to the rest of the body, while the reverse was true for goalkeepers and backs. Upper limb length index was highest among goalkeepers. Slightly shorter upper extremities were characteristic of wingers and pivot players. The latter also stood out because of the highest proportion of abdominal subcutaneous fat in relation to limb adiposity. The distribution index of fat was found to be lowest among goalkeepers.

In terms of body composition, body cell mass was the only variable to show significant intergroup variance, with wingers displaying markedly lower levels than either goalkeepers or pivot players. Body composition characteristics expressed as percentages did not show statistically significant intergroup variance. Body fat percentage was found to be the highest among goalkeepers, while wingers tended to have the lowest percentage of body cell mass.

The results of motor tests varied significantly between goalkeepers and wingers, with the latter exhibiting the lowest physical strength. Backs and pivot players were found to have similar back and hand grip strength.

Table 2. Principal component loadings and correlations between components and original variables

Variable	PC1	PC2	PC3
Eigenvalues	9.65	4.38	1.91
% total variance	43.85	19.89	8.69
Cumulative eigenvalues	9.65	14.02	15.94
% cumulative	43.85	63.75	72.43
Factor loadings			
Body mass	-0.96	0.10	-0.07
Body height	-0.71	0.30	0.47
Leg length	-0.61	0.42	0.50
Arm length	-0.64	0.47	0.49
Chest girth	-0.87	-0.05	-0.10
Hip girth	-0.93	0.02	-0.03
Arm girth	-0.83	0.11	-0.13
Forearm girth	-0.85	0.20	-0.17
Thigh girth	-0.88	-0.12	-0.25
Calf girth	-0.68	-0.04	-0.38
Subscapular skinfold	-0.32	-0.78	-0.16
Supraspinal skinfold	-0.32	-0.84	-0.02
Abdominal skinfold	-0.38	-0.82	0.02
Triceps skinfold	-0.07	-0.73	0.31
Forearm skinfold	-0.23	-0.70	-0.02
Thigh skinfold	-0.64	-0.54	0.26
Medial calf skinfold	-0.60	-0.51	0.24
Fat mass	-0.46	-0.35	-0.10
Body cell mass	-0.84	0.27	-0.14
Extracellular mass	-0.78	0.23	0.14
Hand grip strength	-0.41	0.43	-0.39
Back strength	-0.45	0.54	-0.22

The principal component analysis allowed for the identification of three primary features which offer explanation to about 72% of the total variance (Table 2). The first principal component (PC1) has the biggest share in total variance and correlates strongly with body mass, chest and hip girth, upper and lower extremity circumferences (arm, forearm, thigh, medial calf) and fat free mass (body cell mass and extracellular mass). This component relates to the size and weight of the body and muscular development. In terms of the second principal component (PC2), the subjects can be divided into two categories: those with high physical strength and those with a tendency to accumulate body fat. This component correlates positively with back and hand grip strength and negatively with skinfolds, especially those found on the torso and

forearm. The third component (PC3) relates to slenderness and includes features such as body height and upper and lower limb length.

In Table 3, mean principal component scores of handball players in different positions are shown. It can easily be observed that the only component to exhibit significant variance is PC1. Body size and weight and musculature are noticeably greater among pivot players than among wingers, goalkeepers or backs (Fig. 1). The second principal component did not exhibit significant intergroup variance. Physical abilities associated with PC2 were higher among goalkeepers. In terms of PC3, intergroup variance was found to be very low. It is worth noting that goalkeepers were found to have longer upper extremities in comparison with players in other positions.

Table 3. Mean principal component scores of the handball players from different groups (*p* stands for significance)

Group	G	W	B	P	<i>p</i>
PC1	-0.96 <sup>a</sup>	-3.07 <sup>a</sup>	-0.03 <sup>a</sup>	3.38	0.000
PC2	1.09	-1.02	0.38	-0.66	0.277
PC3	-0.38	0.10	0.06	0.07	0.937

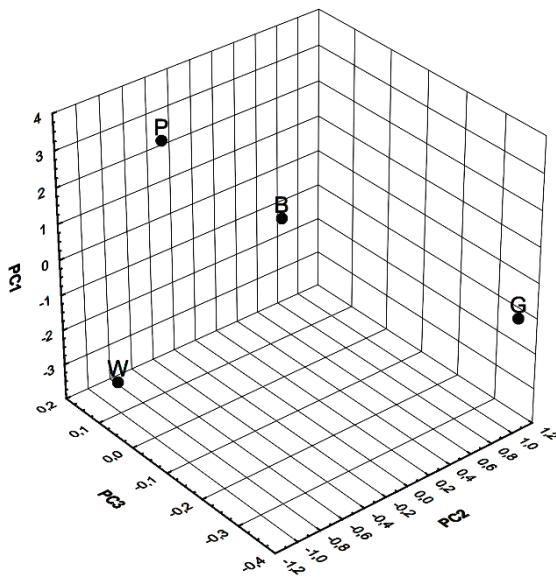


Fig. 1. Principal component analysis scatter plot of handball player profiles (G – goalkeeper, P – pivot, W – wing, B – back)

## 4. Discussion

Body height greater than average is usually the main criterion when selecting handball players in the early stages of training. The body height characteristic

of the professional players used in this study is only found above the 90th percentile for the general population of Poland. The average body mass of the players ranks above the 95th percentile [16]. Even though both traits vary depending on the playing position, the height-to-weight ratio does not show significant intergroup variance. The average BMI of the group was calculated as 26.7, which is considered slightly above the norm and appears to be the result of higher fat free mass among the players. Among the general population, high body mass typically correlates with increased adiposity. When it comes to athletes, however, high BMI results from the development of muscle tissue, which has a higher density than fat [11]. Our research has shown that wingers tended to have the lowest BMI, while pivot players had the highest. These findings are consistent with those of recently published studies of handball players [7], [10], [15], [26].

In comparison with other teams, Polish goalkeepers, wingers and backs had the shortest stature. Pivot players, on the other hand, tended to be taller than their counterparts in world championship teams [7] and the Norwegian national team and first division [10]. In terms of body mass, Polish goalkeepers did not differ significantly from their counterparts in the Spanish professional national league [26]. Polish players were found to have the highest BMI, regardless of playing position.

The diversity in body size and proportions among players results from the specific tasks that each of them has to face. The heavy build and tall stature of pivot players determines their effectiveness on the court, where they face unique tasks associated with being positioned directly in front of the goal area, in between the defenders of the opposing team. Their stature and long upper extremities enable them to effectively block their opponents, increase their reach as well as disorientate opposing defenders and bring chaos in their work; they also provide an advantage in a direct one-to-one confrontation [9]. Their height grants pivots a much wider visual range, while their relatively short legs and low centre of gravity increase their stability [19]. Furthermore, short lower extremities tend to move with a higher frequency, which, in turn, is associated with increased speed over short distances. Naturally, morphological features alone do not make an efficient player; appropriate physical fitness and endurance training are crucial. Nonetheless, they undoubtedly play a significant role in the biomechanical conditioning of motor skills [31].

Goalkeepers tend to be taller than other players and have elongated upper and lower extremities, which enables them to cover a larger area of the goal [12].

Additionally, their low body fat percentage grants them a high level of flexibility. Considering the BMI, backs are characterised by average body frame in terms of size and weight, and low levels of subcutaneous fat on the extremities. They also tend to have an inverted triangle body shape and reduced levels of subcutaneous fat on the limbs, particularly the upper extremities. Backs are the central figures when it comes to directing play [13]. The strong jump shots which they are required to perform take highly developed motor skills and considerable agility. This can clearly be seen in the results of the study, which indicate that the players' upper body kinematics varies during a shot depending on whether they stress one or both of their legs [32]. Wingers were found to be the most slender out of all the players, with the smallest body dimensions. Their relatively low body mass proves an advantage, considering the high level of jumping ability and speed required of players in this position [19]. Athletic physique is of little consequence among wingers, as during a match they do not engage in physical confrontation to the same extent as backs or pivots. In fact, it would prove cumbersome and likely slow them down during a game, preventing them from moving quickly across large distances [18].

An important indicator of physical fitness and health among sports players is body composition. Excessive amounts of fat tissue inhibit dynamic activity and hinder performance, while simultaneously increasing energy requirements. By contrast, lean body generates more power during high-intensity activities and increases endurance. Out of all the examined body composition parameters, the only one to show significant intergroup variance was body cell mass, which is the metabolically active component of fat-free mass. Body cell mass includes muscle, organ and bone tissue, as well as intra- and extracellular water. It is an ensemble of potassium-rich, oxygen-exchanging, glucose-oxidizing and work-performing cells of the body [1]. Our studies have shown that body cell mass is significantly lower in wingers than in goalkeepers or pivot players, which reflects the differences in physical stress associated with particular positions in the team [19]. Goalkeepers were found to have the highest body fat percentage, which is consistent with other studies published on this topic [26].

Other studies have frequently placed emphasis on the role of muscular strength in increasing a player's efficiency and preventing a rapid decline in performance during the final stages of a game [33]. In order to avoid the potential negative effects of strength training, it is now widely believed that this type of training should be tailored to the specific physical demands

associated with a player's position in the team [10], as higher muscular strength and power provide collectively an advantage during shots [9]. Our studies indicate that goalkeepers tend to possess the greatest strength, with wingers at the opposite end of the scale; the results of motor tests were similar among backs and pivot players. These findings are consistent with the literature on the topic [13].

Effectiveness in handball depends largely on the individual skills of the players as well as on their ability to work together within the team. Technical and tactical abilities are considered crucial; however, well-developed motor skills play an important role in increasing a player's performance. The principal component analysis revealed interesting correlations in the structure of the morphological and strength features under study. Differences in physical stress are reflected in the functional and physical features of handball players, as evidenced by the intergroup variance of PC1, which characterises body build. This variable correlates with somatic characteristics which determine outstanding physiological and motor features [29]. The velocity and precision of shots correlate with anthropometric variables such as body mass and height, fat free mass, BMI, hand size and arm span, as well as physical fitness characteristics, especially power and strength [4]. The second principal component (PC2), associated with strength, does not vary significantly between the groups. Goalkeepers were found to have the greatest hand grip and back strength. Studies have shown that increasing the strength and stability of the lumbo-pelvic region improves throwing velocity, which is considered to be one of the most important factors in scoring a goal [17]. The third component (PC3), which correlates with body height and upper and lower limb length does not show statistically significant variation between particular playing positions, although it clearly highlights the morphological distinctiveness of goalkeepers, who have noticeably the longest extremities when compared with players in other positions [12].

## 5. Conclusions

Drawing on the results of the study, it may be safely concluded that the individual requirements associated with different playing positions determine the morpho-functional profile of handball players. Pivots have, by far, a larger body frame, more powerful physique, more subcutaneous fat on the torso and relatively short lower limbs. Superior hand grip strength and back strength

are highly distinctive features of goalkeepers, together with a high limb-to-stature ratio. Backs tend to have an android body type and reduced subcutaneous fat and, like pivots and goalkeepers, a large body cell mass. Wingers, on the other hand, are lean, their limbs are of average length; percentage-wise, their fat levels are very low, whereas the level of extracellular mass is very high. In terms of playing positions, the differences between players are minor and statistically insignificant if the conclusions are based on only one-dimensional analysis.

Consequently, the results of the principal component analysis were a notable and valuable addition, which supplemented the study of morphological and strength differences; this allowed for a reduction of the multidimensional structure to three variables describing body frame: adiposity, strength, as well as limb-to-stature ratio. This approach offered the advantage of highlighting morphological and functional differences between players, depending on their on-court position. Using the results provided here, handball coaches would be able to choose their young players for their most appropriate playing positions according to their anthropometric and physical performance variables.

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## Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship and/or publication of this article.

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