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# Diversity in body composition, segmental muscle mass distribution and isometric strength in team sports

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**Abstract**

*Purpose:* Regular training causes the human body to adapt to the load, and specific changes occur in the soft tissues affecting the body composition. In this study, we analyzed differences in body composition, segmental muscle mass and isometric strength in soccer players, basketball players, handball players and volleyball players.

*Methods:* Height and weight were measured in 96 men aged 20.7±1.88 years training in academic sports clubs in Wrocław (Poland): football (n=24; age: 20.3±1.08 years), basketball (n=24; age: 20.9±1.83 years), handball (n=24; age: 21.2±1. 90 years) and volleyball (n=24; age: 20.3±1.06 years). Body composition was assessed using BIA and SBIA. Motor tests were conducted to assess grip strength and back strength.

*Results:* It occurred that soccer players are characterized by significantly lower height. Handball players have higher body cell mass and better results in strength tests. Additionally, they have a less muscular torso and more strongly muscled legs. Basketball players, handball players and volleyball players are characterized by a more muscular right side of the torso. Football players are distinguished by greater muscularity of the right lower limb. Among volleyball players, greater muscularity of the right upper limb was noted. In football, handball and basketball players, significantly greater right hand strength was observed.

*Conclusions:* It can be concluded that training load in team games shapes specific differences in body composition and isometric strength. Team game players also tend to develop directional asymmetries in the musculature of body segments and grip strength.

**Keywords:** asymmetry; body composition; muscle mass distribution; team sports

## 1. Introduction

Somatic structure and body proportions are different in athletes of particular sports. Similar variation is observed in the body composition of the athletes, as studies have shown that the proportions of fat and lean body mass are important for athletic performance, especially in endurance sports and weightlifting [28].

Team games require players to execute high-intensity actions, which requires increased physical and physiological effort, as well as tactical and technical skills. In addition, during matches, players are required to make quick decisions and perform offensive and defensive tasks efficiently. The nature of particular sports (field size, playing system, competition time, and skills) can affect body morphology in these disciplines. A study of professional Spanish first-division players found differences in anthropometric and physiological variables between handball players, basketball players, and volleyball players. Assessing this differentiation seems crucial for improving talent identification processes and developing appropriate training strategies [20]. Team game players are often characterized by higher-than-average height and weight and lean body mass [14]. In addition, it should be remembered that ball games require sport-specific movement patterns, such as kicking, punching, throwing, or serving the ball, etc., which promotes changes in active muscles, generating differences in muscle mass distribution between body segments [29]. In contrast, the lack of regular exercise load results in no significant differences in relative upper limb muscle size assessed by MRI in non-training men and women [8]. Studies of soccer players have shown that an important factor in determining body composition is the age of the player. In the older players, it was found that their dominant limbs, supporting limbs as well as trunk had a higher fat-free mass content compared to the younger players. The younger group, on the other hand, showed significant differences in fat mass content at different stages of the macrocycle. The authors of a review of articles presenting studies of variation in body composition characteristics in handball players noted that assessment of body fat and skeletal muscle content, in particular, is crucial in this sport, and the results of studies of professional players can help optimally prepare players for the physiological demands of handball [13]. The body fat content of basketball players shows variation depending on the gender of the players, the level of competition, and the measurement method used. Female basketball players are characterized by greater fat mass compared to male players. Athletes presenting at an international level have lower fat mass compared to lower-ranked athletes [26]. A similar analysis of body fat data performed for volleyball players confirmed the dominance of this component in female athletes. The methods used to estimate fat mass (body fat calipers, BIA, DXA, densitometry) gave different results. The highest fat values were obtained with DXA, while the lowest were obtained with body fat calipers measurements. Body fat mass showed a gradient according to sports competence. The lowest fat mass was observed in players presenting at the international level compared to players from lower leagues [15].

Another factor influencing the formation of differences in the size of the muscle mass of body segments is behavioral lateralization, manifested by directional asymmetry of morphological features. Its level is a consequence of differences in mechanical loads on the dominant limb, which lead to deviations from the usual symmetry [11]. Studies have shown that uneven exercise load can also cause asymmetric bone and muscle development in the dominant limb of both the upper and lower limbs [23]. In addition, asymmetric use of the upper extremities contributes to the appearance of lower extremity asymmetry in the opposite direction [11].

An evaluation of the variation in the muscular size of individual body segments in athletes training baseball, soccer, tennis, and lacrosse has shown that players are characterized by specific distributions of muscle mass [34]. Lacrosse, baseball, and tennis players show strong forearm muscle development due to the nature of these sports. In contrast, football players showed stronger development of lower limb musculature and greater asymmetry between the dominant and non-dominant lower limbs. It is worth mentioning that both male and female field hockey players showed significant increases in muscle mass and bone mineral density on the left side of the body [10].

Handball players, on the other hand, showed sacral asymmetry and significant bilateral discrepancies in the size of the musculature of the right and left sides of the entire body and trunk. In contrast, there were no statistically significant differences in muscle mass between the right and left lower and upper limbs [11]. The application of X-ray absorptiometry and computed tomography to the study of professional football players in the Australian Football League has shown the effect of training on the morphology of the musculoskeletal system of the lower body. Long-term exposure to routine exercise, and the strong gravitational loads exerted on the supporting limb, resulted in an increase in the weight of the lower leg bones and an improvement in their structure manifested in an increase in cross-sectional area and thickness of the cortical layer [7]. A segmental analysis of the body composition of female volleyball players in terms of sports level confirmed that body composition parameters are part of the structure of sports performance in volleyball. The highest values for lean body mass and muscle mass characterize the professional athletes. The study conducted on basketball players showed that in the group presenting a lower level of athleticism, a greater asymmetry index characterized not only lean mass but also fat mass in the upper and lower extremities [3].

Asymmetry in muscular size is reflected in motor skills. Bell et al. [2] analyzed the effect of force and power asymmetry on countermovement jump performance in collegiate athletes. The study included athletes representing field hockey, golf, soccer, volleyball, and softball. Asymmetry in fat-free mass in the lower limbs was found to be partly responsible for the asymmetry in strength and power generated during the jump. Another article presented the results of an analysis indicating that Australian football players were more effective shooters when they were characterized by greater symmetry in the amount of fat-free mass between their kicking and supporting limbs [6]. Čvorović A. [4], on the other hand, analyzed the question of whether playing basketball generates unequal limb use compared to the non-sporting population. The study tested the explosive strength of the lower and upper limbs, as well as reaction time and agility. Basketball was found to have a positive effect on the development of the functional variables studied, also reducing the level of asymmetry in athletes compared to the control group. The presented research review shows that team sports such as handball, volleyball, basketball, and soccer have not yet been sufficiently described in scientific papers to address the problem of muscular distribution, morphological asymmetry, and isometric strength. The team games analyzed are characterized by significant asymmetry of body movements, so we believe it is reasonable to hypothesize that characteristics of soccer, basketball, volleyball, and handball effort loads, and movement patterns generate differences in body composition, distribution of muscle mass between body segments, and magnitude of isometric strength. The purpose of this study was to investigate the differentiation of body composition components, muscle mass asymmetry, and isometric strength in players of selected team games.

## 2. Materials and Methods

### 2.1 Participants

The study included 96 men aged 20.7±1.88 years training in academic sports clubs in Wrocław (Poland): football [F] (n=24; age: 20.3±1.08 years), basketball [B] (n=24; age: 20.9±1.83 years), handball [H] (n=24; age: 21.2±1. 90 years) and volleyball [V] (n=24; age: 20.3±1.06 years). The analysis of variance did not show statistically significant differences in the calendar age and training experience of the subjects. The training experience in each group was respectively: football 8.1±0.99 years, basketball 7.8±2.4 years, handball 8.8±1.43 years, and volleyball 7.9±2.77 years. All players presented the same sport level: academic sports.

### 2.2 Measurements and calculations

Measurements were taken in the morning during the preparation period (the recruitment period was 1.02.2022 – 15.12.2023) and in the Central Research Laboratory of  Wroclaw University of Health and Sport Sciences, Poland (Quality Management System Certificate: PN-EN ISO 9001:2015 - Certificate Reg. No.: PW-15105-22X). All volunteer participants visited the laboratory once and underwent anthropometric and strength measures. A survey technique was used to gather information on date of birth, length of training experience, dietary supplements used, and presence of injuries.

The research was carried out by specialists in anthropometry. Body height was measured with an anthropometer to the nearest 0.1 cm (GPM Siber Hegner Machinery Ltd., Zurich, Switzerland). Body weight was assessed using an electronic scale with an accuracy of 0.1 kg (Fawag, Lublin, Poland). Height and weight were used to assess height-weight ratios. For this purpose, the height-weight ratio (HWR; height [cm] / mass [kg]$^{0.333}$) also known as reciprocal ponderal index, was calculated [16].

Body composition was examined using the electrical bioimpedance method (SF - BIA single-frequency bioimpedance analysis using electrical bioimpedance analysis using a current frequency of 50 kHz). An analyzer with a built-in BodyScan module – BIA-101 Anniversary Sport Edition from Akern (tetrapolar and octopolar versions, hand-foot electrode array, BodyGram 1.31 software, BodyScan 5.0 software; Florence, Italy) was used. The analyzer employs an 8-point, bilateral, hand-to-foot electrode configuration. Prior to electrode placement, the attachment sites were cleaned with alcohol pads. Adhesive electrodes were then positioned on the dorsal surfaces of both hands and both feet. The proximal palm electrode was placed between the radial and ulnar styloid processes, directly superficial to the distal radial-ulnar joint and the distal palm electrode was placed superficial to the metacarpophalangeal joint of the third phalanx. The proximal foot electrode was placed directly between the medial and lateral malleoli at the ankle. The distal foot electrode was placed immediately proximal to the second and third metatarsophalangeal joints. Each participant remained in the supine position for ~ 5 min prior to assessment. Body composition measurements were taken following the manufacturer's recommendations (the subjects were fasted, during the measurement they were in the supine position, limbs rested loosely at an angle of about 40° to the trunk, the time distance between the measurement and intense exercise was at least 12 hours).

The bioelectrical impedance analysis has advantages similar to the anthropometry, because it is convenient for the patient, inexpensixe, safe and it is a potential field and clinical method for evaluating skeletal muscle mass and fat. In addition to that, body composition measurements performed with it are fairly rapid, non-invasive and reproducible. It can be used in both healthy and diseased individuals in any age category. BIA testing involves measuring impedance, or electrical resistance, which consists of the resistance and reactance of soft tissues through which an electric current is passed of low intensity [21]. BIA has been used in the large scale studies of body composition and assessment of body fluid status. The technique has been used extensively in studies of disorders of nutrition, for predicting the risk of diseases cardiovascular and metabolic, or in sports medicine. 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.

The following variables were included in the analysis: fat mass [FM], body cell mass [BCM], extracellular mass [ECM], and muscle mass expressed in kilograms and percentages of body weight. The size of the muscularity of the segments (trunk, upper and lower limbs) on the right (R) and left (L) sides of the body was also estimated. The muscle mass on the right side of the trunk was calculated by subtracting the muscle mass on the right lower and upper limbs from the total muscle mass on the right side of the body. The muscle mass on the left side of that body segment was calculated using the analogous method. The muscularity of each body segment was expressed in kilograms and percentages of total muscle mass.

The grip strength of the right (R) and left (L) hands and the strength of the back muscles were also measured. Grip strength plays an important role in throwing and casting the ball. Grip strength was measured with the use of the hand grip dynamometer (T.K.K.5001, Takei Scientific Inst. Co., Ltd., Niigata, Japan). The aim of this test was to measure the maximum isometric strength of the muscles in the palm and forearm. During the measurement, the straightened upper limb was directed toward the ground [18]. The players performed 3 repetitions at maximum intensity with a 30-second rest between trials to minimize the effects of fatigue. Peak developed strength in kilograms [kg] was recorded. The maximal isometric back extensor strength (kg) was measured by using a back and leg dynamometer (T.K.K.5402, Takei Scientific Inst. Co., Ltd., Niigata City, Japan). The subjects stood on the base of the dynamometer and legs and backs were straightened to allow the bar to be at the level of the patella [17]. Each volunteer also performed 3 trials with a rest of 30 seconds between each trial. The highest score of the trials was recorded in kilograms.

## 2.3 Statistical analysis

Calculations were performed using the Statistica™ 13.3 package (TIBCO Software Inc., Santa Clara, United States). The homogeneity of variance of the analyzed traits was tested using Levene's test. Intergroup variation in the level of development of the analyzed traits was assessed using analysis of variance and Tukey's *post hoc* RIR test. A t-test for dependent samples was used to assess bilateral differences in muscular size. The alpha level was set at $p < 0.05$. A ternary plot was used to examine the relationship between the three components of body composition (FM, BCM, ECM) in groups of players. The distribution of individual competitors' points in the three body composition variables system was assessed using the $\chi^2$ test.

The use of cluster analysis made it possible to present the structure of the variables considered in the work in each group of players. In this study, distances were calculated using Pearson's 1-r formula. The clustering was carried out using Ward's method. A dendrogram (a graphical representation of the ordering of a set of features) shows characteristic groups that are the least different from each other (minimum variance within clusters) and are connected at the appropriate level of similarity. The division of the dendrogram was based on an analysis of the consequences that result from the intersection of the taxonomic pyramid at different levels. The best solution is to divide a height that precedes a significant reduction in the similarity between objects or clusters [33].

## 3. Results

The intergroup variation in body weight is not statistically significant (Table 1). The lowest values of this trait characterize football players, the highest values were found in the group of handball players. Body height shows significant intergroup differences. Football players are characterized by significantly lower body height compared to other groups. Basketball and handball players showed similar body heights, while volleyball players dominated the size of the trait in question.

Table 1. Statistical characteristics and inter-group differences of the morphological traits and grip strength in football (F), basketball (B), handball (H) and volleyball (V) players.

| Group | F | B | H | V | *p* |
|---|---|---|---|---|---|
| Variable | Mean (SD) | Mean (SD) | Mean (SD) | Mean (SD) | |
| Body height [cm] | 179.8 (5.98)[abc] | 185.2 (7.77) | 185.3 (6.17) | 186.2 (6.71) | 0.004 |
| Body mass [kg] | 76.8 (8.49) | 80.6 (11.91) | 83.9 (9.32) | 80.8 (9.00) | 0.101 |
| HWR | 42.4 (1.09) | 43.0 (1.61) | 42.4 (1.00) | 43.1 (1.03) | 0.130 |
| % Fat mass | 19.6 (3.54) | 19.8 (5.35) | 17.6 (3.53) | 19.4 (3.01) | 0.183 |
| % ECM | 36.1 (5.42) | 36.5 (5.01) | 34.2 (3.52) | 36.9 (6.56) | 0.291 |
| % BCM | 44.3 (6.15)[b] | 43.8 (6.16)[b] | 48.1 (4.53) | 43.5 (7.30)[b] | 0.034 |
| % Muscle mass | 63.0 (4.94) | 61.3 (4.03) | 62.6 (3.68) | 61.3 (3.43) | 0.296 |
| Segmental muscle mass | | | | | |
| Right body [kg] | 24.3 (2.9) | 24.9 (3.9) | 26.7 (3.3) | 25.0 (3.4) | 0.072 |
| Left body [kg] | 23.8 (2.6) | 24.4 (4.3) | 25.8 (3.3) | 24.2 (3.2) | 0.200 |
| Trunk [kg] | 26.5 (3.0)[c] | 28.1 (3.2) | 26.8 (2.8) | 28.7 (3.5) | 0.043 |
| Right trunk [kg] | 13.7 (1.7)[c] | 14.6 (2.0) | 14.0 (1.8) | 15.0 (2.0) | 0.042 |
| Left trunk [kg] | 12.9 (2.0) | 13.5 (1.7) | 12.8 (1.6) | 13.7 (1.8) | 0.168 |
| Right arm [kg] | 3.5 (1.2) | 3.7 (1.6) | 3.9 (0.9) | 3.5 (1.1) | 0.517 |
| Left arm [kg] | 3.9 (1.7) | 4.0 (2.2) | 4.0 (1.2) | 3.5 (1.5) | 0.679 |
| Right leg [kg] | 7.1 (1.6)[b] | 6.7 (2.0) | 8.8 (2.5)[ac] | 6.6 (1.6) | 0.000 |
| Left leg [kg] | 7.1 (1.7)[b] | 7.0 (2.5) | 9.0 (2.5)[ac] | 6.9 (1.6) | 0.002 |
| % Right body | 50.4 (1.3) | 50.6 (2.1) | 50.9 (2.6) | 50.8 (1.2) | 0.764 |
| % Trunk | 55.5 (6.1) | 57.9 (8.8) | 51.5 (7.1)[ac] | 58.8 (6.7) | 0.003 |
| % Right trunk | 28.6 (3.4) | 30.0 (4.9) | 26.9 (3.9)[ac] | 30.6 (3.5) | 0.006 |
| % Left trunk | 26.9 (4.3) | 27.8 (4.6) | 24.6 (4.0)[ac] | 28.2 (3.8) | 0.016 |
| % Right arm | 7.2 (1.9) | 7.2 (1. 9) | 7.4 (1.2) | 6.9 (1.6) | 0.757 |
| % Left arm | 7.9 (3.4) | 7.7 (3.0) | 7.5 (1.7) | 7.0 (2.3) | 0.550 |
| % Right leg | 14.6 (2.3)[b] | 13.4 (2.6) | 16.6 (3.1)[ac] | 13.3 (2.2) | 0.000 |
| % Left leg | 14.7 (2.6)[b] | 13.8 (3.4) | 16.9 (3.0)[ac] | 14.0 (2.2) | 0.001 |
| Strength | | | | | |
| Right hand [kG] | 48.6 (6.3)[b] | 53.1 (9.7) | 56.4 (9. 6)[c] | 49.6 (7.2) | 0.005 |
| Left hand [kG] | 45.8 (6.5)[b] | 50.4 (9.3) | 52.2 (8.7) | 46.7 (8.5) | 0.024 |
| Back [kG] | 123.1 (12.4)[b] | 129.5 (12.8)[b] | 141.5 (19.9) | 130.9 (16.9) | 0.000 |

[a] significantly different from B; [b] significantly different from H; [c] significantly different from V

Legend: BCM = body cell mass; ECM = extracellular mass; HWR = height-weight ratio;

Height-for-weight proportions and the percentage of fat in body weight do not significantly differ between the tested groups of athletes. Lower HWR values characterize football and handball players, while volleyball and basketball players are characterized by higher values of the aforementioned index and a slimmer physique. The mean values of the percentages of fat mass and extracellular mass show no statistically significant intergroup variation. A slightly higher percentage of fat characterizes volleyball players. Basketball and volleyball players, on the other hand, have slightly higher extracellular mass values. In contrast, the percentage of cell mass is significantly higher in handball players compared to the other groups. The distributions of the athletes' scores across the three body composition variables (fat mass, extracellular mass, cell mass) as assessed by the $\chi^2$ test ($\chi^2$=47.21, p<0.05) also show statistically significant intergroup differentiation (Fig 1).

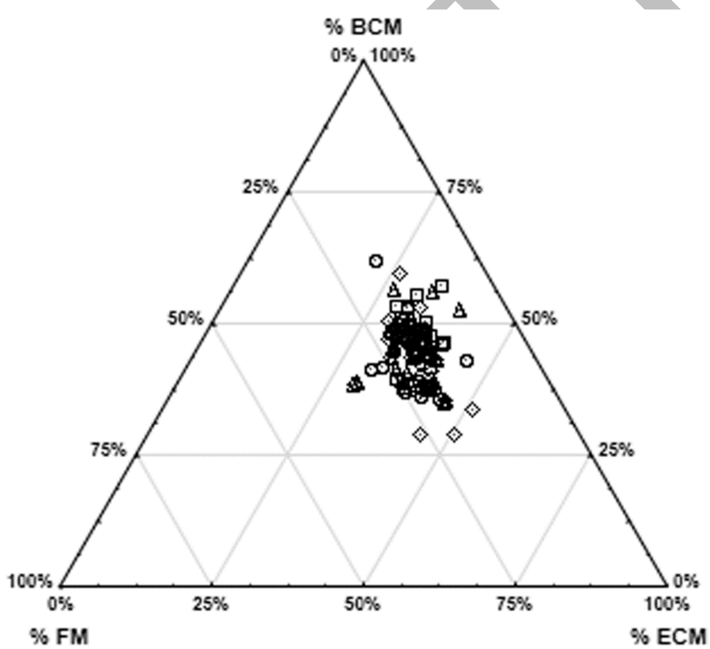


Fig. 1. Distribution of players in the system of three variables of body composition (○ – football, Δ – basketball, □ – handball, ◊ – volleyball).

The intergroup variation in muscle mass expressed as a percentage of body weight is statistically insignificant. The greatest muscle mass is characteristic of football and handball players, and the smallest of volleyball players. The intergroup variation in muscle mass on the right and left sides of the body expressed in kilograms and percentages of total muscle mass is also at a low level. Trunk muscle mass expressed in kilograms and percent of total muscle mass shows statistically significant intergroup variation. A significantly lower percentage of trunk muscle mass in total musculature characterizes handball players compared to volleyball and basketball players. Similarly, the musculature of the right and left sides of the trunk of these players is at a significantly lower level compared to the basketball and volleyball groups.

The musculature of the upper limbs is at a similar level in the tested representatives of team games and shows no statistically significant variation. The lowest average values were recorded in the group of volleyball players. The greatest muscle mass of the upper extremities characterizes handball players. Intergroup variation in lower limb musculature is shaped differently. Both muscle mass expressed in kilograms and as a percentage of total muscle mass is significantly higher in the handball group compared to football, basketball, and volleyball players.

The grip strength of the right hand in the group of handball players is significantly higher compared to football and volleyball players. In the case of the left hand, statistically significant dominance of handball players occurred only when comparing them with football players. Handball players also have significantly greater back extensor strength compared to football and basketball players.

In all groups, muscle mass on the right side of the body and trunk is greater compared to the left, but only in volleyball players is the difference statistically significant (Table 2). Basketball, handball, and volleyball players are characterized by significantly greater muscularity of the right side of the trunk. Bilateral differences in the size of upper and lower limb musculature do not reach the threshold of statistical significance. Within the upper extremities, only volleyball players have a slightly more heavily muscled right limb compared to the left. Football players are characterized by slightly greater muscularity of the right lower limb, while the other groups are marked by slightly greater massiveness of the left leg. Significantly greater strength of the right hand characterizes football, handball, and basketball players was observed. In the group of volleyball players, the dominance of the right hand is statistically insignificant.

Table 2. Bilateral differences in muscle mass of body segments and grip strength (GS) in football (F), basketball (B), handball (H), and volleyball (V) players.

| Group | F | | B | | H | | V | |
|---|---|---|---|---|---|---|---|---|
| Variable | MD (SD) | *p* | MD (SD) | *p* | MD (SD) | *p* | MD (SD) | *p* |
| Body R-L | 0.4 (1.3) | 0.100 | 0.5 (2.2) | 0.286 | 1.0 (2.9) | 0.118 | 0.8 (1.3) | 0.002 |
| Trunk R-L | 0.8 (2.2) | 0.069 | 1.1 (1.9) | 0.010 | 1.2 (2.0) | 0.007 | 1.2 (1.6) | 0.000 |
| Arm R-L | -0.3 (1.7) | 0.304 | -0.3 (0.9) | 0.094 | -0.1 (0.8) | 0.814 | 0.1 (0.5) | 0.711 |
| Leg R-L | 0.1 (0.9) | 0.849 | -0.3 (1.0) | 0.183 | -0.2 (0.9) | 0.334 | -0.4 (1.1) | 0.088 |
| GS R-L | 2.8 (3.5) | 0.000 | 2.7 (5.1) | 0.016 | 4.3 (7.7) | 0.012 | 2.9 (7.4) | 0.052 |

abbreviations: GS = grip strength; MD = mean difference between right (R) and left (L) side of the body

The dendrograms show the hierarchical structure of the analyzed variables based on the decreasing similarity of these characteristics (Fig 2). In the group of soccer players, the analyzed characteristics form four clusters. The first cluster consists of measurements of hand grip strength loosely linked to a two-element ensemble that includes the musculature of the left upper limb and the right half of the trunk. Another focus was the muscle mass of the left half of the trunk and back strength. The last focus is formed by the strongly interconnected muscle mass of the lower limbs and the musculature of the right upper limb. In the basketball group, the structure of the first cluster includes the strength of the right and left hands. The next cluster includes strongly interconnected two-element clusters involving the musculature of the upper and lower extremities. The third cluster included back strength and muscle mass of the right and left sides of the trunk. Among volleyball players, the hierarchical structure of traits is similar to that observed in basketball players. The first cluster included measurements of hand grip strength. The second four-element unit is made up of the strongly interconnected musculature of the upper and lower extremities. Unlike in basketball players, the tying distance for the muscularity of the lower limbs exceeds the corresponding value for the upper limbs. The third cluster consists of trunk musculature and back strength. In handball players, measurements of right and left-hand grip strength and back strength form a single cluster. Attached to it is a two-piece unit that includes the musculature of the right and left sides of the trunk. Connected to the mentioned group is a four-element focus involving the musculature of the limbs. Unlike that noted for volleyball players, the binding distance for the lower extremities is significantly lower compared to the upper extremities.

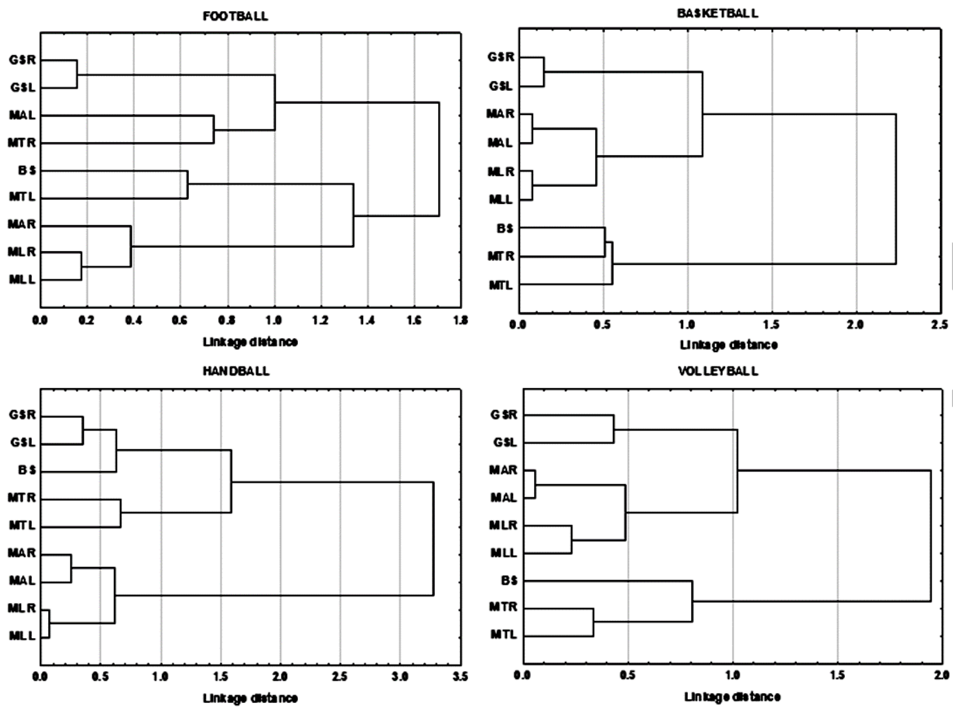


Fig. 2. Cluster analysis of musculature of body segments and strength in football, basketball, handball, and volleyball athletes. Legend: BS = back strength; GSL = grip strength left; GSR = grip strength right; MAL = muscle arm left; MAR = muscle arm right; MLL = muscle leg left; MLR = muscle leg right; MTL = muscle trunk left; MTR = muscle trunk right

## 4. Discussion

The results confirmed the hypothesis that the unique characteristics of exercise loads in soccer, basketball, volleyball and handball, as well as movement patterns, generate differences in body composition, distribution of muscle mass between body segments and magnitude of isometric force.

The body heights of basketball, volleyball, and handball players are at similar levels, which is confirmed by another study of university-level male players [9]. The low intergroup differences observed may be because the athletes studied presented a lower sportive level, so the selection pressure in being selected for a particular sport was weaker. It should be noted that studies of elite professional teams indicate the prevalence of significantly greater body height in basketball players and the lack of similar variation between volleyball and handball players [20]. Similarly, as shown in other studies, football players were found to be significantly shorter compared to players in other groups [22]. As expected, body weight does not significantly differentiate the athletes tested. The reciprocal ponderal index, which, according to researchers, better characterizes the morphology of athletes than the body mass index [16], was chosen to assess height-weight proportions. Although the differences in HWR are not statistically significant, it should be noted that the basketball and volleyball players surveyed have the greatest body slenderness. Nevill et al. [16] showed that body slenderness increases the chances of success in soccer. Taller and slenderer players are better equipped to play more effectively and direct the ball more efficiently in both defense and offense. Linear body structure also promotes the generation of greater lower limb explosive strength, which is often assessed by vertical countermovement jump and is an important motor variable in handball, volleyball, and basketball [27].

It should be noted that not only height-weight proportions but also body composition affect performance in team games. It has been shown in articles published to date that, in particular, fat-free mass shows significant positive correlations with strength and power, while negative correlations are with fat mass in both percentage and absolute terms [25]. The analysis showed that the athletes studied had similar amount of body fat and extracellular mass, which includes connective tissues such as collagen, elastin, skin, tendons and bone [5]. In contrast, body cell mass, representing the metabolically active portion of fat-free mass [5], showed significant intergroup variation. The percentage of BCM takes substantially higher values in handball players. The analysis also showed that handball players had significantly greater grip strength and back strength compared to volleyball and soccer players, confirming the observations of other authors that BCM is a good predictor of muscular performance and can predict sports performance [1].

Grip strength, which is thought to be a good predictor of overall muscle strength at all ages, is a trait that is relevant to performance in ball-throwing sports [24]. Moderate to high correlations have been reported in the literature between hand grip strength and ball speed during serving in volleyball players and throwing in handball [31]. Similarly, in basketball, high correlations were found between free throw accuracy and grip strength in a group of sub-elite semi-professional basketball players. In soccer, however, moderate correlations have been reported between grip strength and the results of other tests assessing a player's level of strength and power [18]. We found that significantly the highest level of the maximal isometric back extensor strength characterized handball players compared to football and basketball players. Upper body strength plays an important role in volleyball, basketball or handball, as it is necessary for many discipline-specific actions, such as serving, throwing, hitting, blocking, and sliding [24].

There was no significant intergroup variation in total muscle mass, which may be due to the similar sports level of the athletes studied. We found whereas clear differences in the distribution of muscle mass between body segments, which was also confirmed in the work of Yamada et al. [34]. Ball sports require sport-specific movement patterns such as kicking, hitting, throwing, and serving, and generate sport-specific selective muscle [24]. Muscle mass of the trunk shows greater intergroup variation. A higher percentage of trunk muscle mass in total musculature characterizes volleyball and basketball players compared to handball players, as confirmed by another study [14]. The intergroup differences in upper limb musculature is low [8], whereas a significantly greater muscle mass of the lower limbs was noted in handball players compared to other groups.

A certain degree of asymmetry is considered normal and results from lateralization manifested by limb dominance and sport-specific training (e.g., kicking and non-kicking leg strength, throwing and non-throwing upper limbs) [6]. The bilateral differences in muscle mass size found in this study are insignificant and indicate a slight dominance of the right side over the left side of the body. Within the trunk, the differences between right and left side is more pronounced, especially among handball, basketball, and volleyball players [11]. Biomechanical pressures caused by lateralization and motor stereotypes of movement patterns specific to the team games under consideration result in increased directional asymmetry in the lower extremities. Football players are characterized by greater muscularity of the right lower limb due to a preference for using that leg. Surveys of World Cup participants indicate that athletes are as right-footed as the general population (about 79%). Basketball, handball, and volleyball players are marked by a slightly greater massiveness of the left leg due to their preference during jumping and landing [11]. Volleyball and handball players are characterized by greater muscularity of the right upper limb due to its asymmetric use during throwing and serving, confirming the observations of other authors that unilateral actions in team sports increase the imbalance between the limbs, creating a dominant side [12].

In soccer players, hand grip strength shows weak correlations with the muscularity of body segments, which may be because isometric hand strength is a poor predictor of other motor control indices used in this sport [18]. The association of lower limb, right upper limb and left mid-torso musculature and maximal isometric back extensor strength can be justified by the nature of the game, which requires strong upper body stabilization and upper limb work when performing fast and powerful actions such as jumps, sprints, changes of direction. Also, executing free throws from above the head requires strong arm and shoulder muscles [7].

The dendrograms for basketball and volleyball are very similar, confirming the similarities noted in the literature that exist in the movement patterns and physiological requirements of these games [30]. Nonetheless, it should be noted that volleyball players have stronger connections between upper limb musculature compared to lower limb musculature, which is confirmed by the results of other studies [32]. However, on the dendrogram of basketball linkage distances, the musculature of the upper and lower extremities are almost identical. The most common throw during a basketball game is the jump shot. Its execution depends on the work of the upper limbs, as the arm sweep helps achieve a greater jump height, and the lower limbs, which generate a motor ability that is important for a basketball player, the power. Only in the group of handball players are strength measurements a separate cluster. As research has shown, upper body strength plays an important role in handball, as in this sport, setting up blocks and creating gaps in the opponent's defense requires pushing off the body with the hands and stabilizing the entire body in different postural positions [24]. In contrast, hand grip strength shows moderate to high correlations between ball velocity during throwing [31]. In all of the aforementioned disciplines, back extensor strength is linked to trunk musculature that controls movement, ensures stable posture, and protects against injury, especially overload injuries in athletes.

## 5. Conclusions

The results show that players of the studied team games differ in overall dimensions, body composition, muscular distribution, and isometric strength (grip strength, back strength). Football players have significantly lower body heights, while handball players dominate in terms of the size of their body cell mass and the results obtained in strength tests. Although total muscle mass did not significantly differ between the groups studied, significant differences were found in the musculature of body segments. Handball players have a significantly less accumulation of muscle mass on the trunk and much more strongly muscled lower limbs compared to the other groups. Our results show that team game players, using one side of the body more often during training and matches, tend to develop directional asymmetry in the size of body segments muscle mass. Basketball, handball, and volleyball players are characterized by significantly greater muscularity of the right side of the trunk compared to football players. In all groups, bilateral differences in the size of upper and lower limb musculature are insignificant. Nevertheless, soccer players are characterized by stronger musculature of the right lower limb, and among volleyball players, a dominance of musculature of the right upper limb compared to the left side of the body has been noted. Significantly greater strength of the right hand characterizes football, handball, and basketball players was observed. In contrast, in the group of volleyball players, the asymmetry in the magnitude of the right hand's grip strength is insignificant.

Excessive morphological asymmetry can have negative medical and functional consequences. For this reason, assessing the size of bilateral differences is important for coaches and players in the context of prevention. It can be used to identify and minimize risks to athletes' health and mobility. Thus, it is desirable to systematically monitor muscle mass distribution and asymmetry among team game players in light of their practical applications during training. Coaches and athletes should incorporate corrective and symmetrizing exercises into their sports training program, which serves as a compensatory function to optimize their motor potential.



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**Authors' contributions:**

AS - data collection, data interpretation, manuscript preparation, project administration, funding acquisition;

JP - data collection, data interpretation, manuscript preparation, literature search;

AB - study design, data collection, data interpretation, statistical analysis, manuscript and figures preparation, literature search.

All authors reviewed the paper and agreed to the published version of the manuscript.

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