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Anthropometric Characteristics, Maximal Isokinetic Strength and Selected Handball Power Indicators Are Specific to Playing Positions in Elite Kosovan Handball Players

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Abstract: Anthropometric characteristics and physical performance are closely related to the game demands of each playing position. This study aimed to first examine the differences between playing positions in anthropometric characteristics and physical performance with special emphasis on the isokinetic strength of elite male handball players, and secondly to examine the correlations of the latter variables with ball velocity. Anthropometric characteristics, maximal isokinetic strength, sprinting and vertical jumping performance, and ball velocity in the set shot and jump shot were obtained from 93 elite handball players (age 22 ± 5 years, height 184 ± 8 cm, and weight 84 ± 14 kg) pre-season. Wing players were shorter compared to other players, and pivots were the heaviest. Wings had the fastest 20 m sprints, and, along with backcourt players, jumped higher, had better maximal knee isometric strength, and achieved the highest ball velocity compared to pivots and goalkeepers, respectively. There were no significant differences between playing positions in unilateral and bilateral maximal leg strength imbalances. Ball velocity was significantly correlated with height, weight, squat jump and maximal torque of extensors and flexors. Our study suggest that shooting success is largely determined by the player's height, weight, muscle strength and power, while it seems that anthropometric characteristics and physical performance are closely related to the game demands of each playing position.

Keywords: morphology; isokinetic; sprints; vertical jump performance; handball shooting

1. Introduction

Handball is an Olympic team sport [1,2], split into two periods (each 30 min long) and consisting of a high degree of body contact and predominantly aerobic activities separated by anaerobic bouts of sprints, jumps, throws, changes of directions in the offense (counterattack and attack buildup) and defense [2,3]. Therefore, competition success in elite handball is not only closely related to the technical and tactical skills of each individual or team, but also to the players' anthropometric characteristics, physical performance (e.g., maximal strength and power as measured using strength, sprinting, and jumping tests), and handball shooting performance [3–5].

To date, only a few studies evaluating the physical and physiological demands in handball matches have shown significant differences between playing positions [6–8]. Results obtained during gameplay have shown that backcourt players cover larger distances and spend less time standing and walking, and, together with pivots, have higher in-game heart rates and spend longer durations at higher intensities (>80% maximal heart rate) [7]. In contrast, wing players are faster than other playing positions, and pivots endure more body impact than other players [6]. Furthermore, similar differences between playing positions were also obtained in anthropometric characteristics [9,10] and physical performance [11–16]. Wings are the shortest, have significantly lower body mass and body mass index (BMI) than other players; pivots are the heaviest, whereas other playing positions do not differ in height [9–16]. Research comparing playing positions in sprinting (e.g., sprints on 20–30 m) and jumping performance (squat jump (SJ) and/or countermovement jumps (CMJs)) is relatively scarce, and there are some discrepancies in sprinting times and jump heights among studies [11,14–16]. Nevertheless, backcourt players and wings demonstrated the fastest sprinting times [14,15], while CMJ height was the highest in wings [14], compared to pivots and goalkeepers [15].

Isokinetic dynamometry has long been the gold standard for assessing changes to an athlete's maximal muscle strength/torque during the season [17,18] and risk of injury (measured as imbalances between agonist and antagonist muscles or bilateral differences) in different types of a team sport [19]. In the past, only a few studies have evaluated isokinetic maximal knee strength and strength imbalances in male handball players [19–21], with the majority of studies having been performed on female handball players, focusing on shoulder muscle strength, and several on knee muscle strength in relation to shoulder and knee injuries [18,22–25]. Evidence from two studies evaluating isokinetic maximal strength in male handball players has suggested no differences between dominant and nondominant lower limb knee extensor and flexor strength, as well as normal hamstring-to-quadriceps ratio on both limbs at 60°/s and 180°/s [19,20]. However, no studies in handball have investigated isokinetic maximal strength of the knee joint according to playing position. Furthermore, it also remains to be elucidated the potential role of playing position on development of muscle strength imbalances between and within legs as a product of specific game demands. Such findings would serve as excellent feedback to practitioners to focus on preventing potential injuries and to improve player performance.

Ball velocity has been recognized as one of the most important determinants of game performance [14]. Maximal ball velocity is achieved through a proximal-to-distal manner; this movement allows momentum of force to transfer from the lower limb and/or pelvis through the trunk to the throwing arm, thereby enabling higher velocities of the shot [26]. During the game, the majority of shots are performed using two shooting techniques: a three-step jump shot and a standing set shot from the ground. Both techniques use two different kinetic strategies (braking the body with lead leg in the standing set shot vs. opposed leg movement during the flight phase of the three-step jump shot) [27,28], while ball velocity in both is influenced by an optimal proximal–distal principle, trunk movement, and maximal arm rotation [26,28]. It is well established that elite players are able to maintain an optimal proximal-to-distal principle and arm movement while performing different shooting techniques [27]. Lower ball velocity has been associated with lower strength in the lower and upper limbs, leading to inefficient transfer of power from the proximal (pelvis, trunk) to distal (shooting arm) parts of the body [29]. Backcourt players and wings shoot the ball faster compared to pivots or goalkeepers [14,15,30]. For overhead throws, only inconsistent correlations have been reported between ball velocity and anthropometric characteristics or physical performance, and this is likely due to the complex nature of this movement [10,11,13,31,32]. Body height and weight were the only anthropometric characteristics significantly correlated with ball velocity of the standing shot [11] and/or three-step running shot [10,13,31], whereas two additional studies reported significant correlations with lower limb strength (1-RM half back squat) [31], standing long jump, 30 m sprint, and maximal oxygen uptake (estimated from 20 m shuttle run) [31]. Other studies have failed to detect such correlations [11,13]; therefore, additional studies are warranted to transfer these findings into training settings.

Based on the identified gaps in the knowledge of the anthropometric characteristics, maximal strength and power performance, and handball shooting performance of elite handball players, our study consisted of three aims. The first aim of the study was to provide further evidence on the isokinetic maximal strength and potential limb imbalances between playing positions in elite male handball players. The second aim was to examine the differences in anthropometric characteristics, sprinting and vertical jump performance between playing positions, and the last aim was to investigate the correlations between handball-specific performance (e.g., ball velocity) and selected anthropometric characteristics and physical performance indicators.

2. Materials and Methods

2.1. Study Design

The study was designed as a cross-sectional study of a sample of elite Kosovo handball players. Measurements were conducted two weeks before the start of a competitive season, at the end of August 2019. Testing procedures were split into three days. On the first day anthropometric characteristics (height, weight, wingspan, and thigh circumference) and body composition (skeletal muscle mass and fat mass) were measured, and familiarization with all testing procedures was conducted. On the second day, following a standardized warm-up procedure, sprinting performance (20 m sprints), vertical jump performance (CMJ and SJ), and shooting performance (shooting velocity of three-step set shot and jump shot) were assessed. Finally, during the last day measurements of unilateral isokinetic knee flexor and extensor torque at 60°/s and 180°/s were conducted after the standardized warm-up. Forty-eight hours of rest were given between the second and third testing day to minimize any potential effects of fatigue. Testing procedures were performed by experienced strength and conditioning specialists.

2.2. Subjects

A total of 93 elite male handball players from Kosovo's first handball league were enrolled into the study, age (mean (SD)) 22 (1) years, height 184.0 (7.83) cm, weight 84.10 (13.74) kg, and with 8 (4) years of professional playing experience. The sample consisted of 35 (37.63%) backcourt players, 26 (27.96%) wing players, 15 (16.13%) pivots, and 17 (18.28%) goalkeepers. Playing positions were determined according to registration data obtained from the Handball Federation of Kosovo. Players' adherence was consistent throughout the study, and no injuries or other health issues were reported.

Prior to enrolment into the study, we informed all participants about the aims of our study, methods and procedures, and potential testing risks. Measurements were performed at the end of the last week of the specific preparation phase for the upcoming season, with at least 48 h of rest after the last training session, and 10–14 days prior to beginning of the season. The exclusion criteria were: fewer than two years of professional playing experience, age younger than 18 years, and any recent musculoskeletal injuries (<6 months). All participants signed a written consent prior to inclusion in the study. The study design was approved by the Ethics Committee of Universi College Prishtina (document number: 488/18), while the study was conducted according to the Declaration of Helsinki guidelines for the use of human participants.

2.3. Procedures

2.3.1. Anthropometric and Body Composition Measurement

Prior to physical performance measurements on the first testing day, anthropometric and bioimpedance measurements were obtained according to the international guidelines [33]. Body height and weight were measured while standing barefoot using a SECA 763 stadiometer with electronic scale (Seca Instruments Ltd., Hamburg, Germany) to the nearest cm and kg, respectively. The wingspan was measured using a horizontal wall-mounted scale to the nearest cm, with arms abducted at 90° from a neutral position and back facing towards the wall, and thigh circumference was measured using a tape

measure while standing at 2/3 of the distance between the lateral epicondyle of the knee and the greater trochanter on the dominant leg. Skeletal muscle mass and fat mass measurements were obtained using a Biospace Inbody 720 bioimpedance device (Inbody Co., Leicester, United Kingdom). Participants were asked to place toes and heels on the anterior and posterior electrodes of the weighting platform, and to firmly grasp the hand grip with both hands. Measurements were taken early in the morning, and participants were advised to avoid any moderate to vigorous physical activity a day before the measurement [34].

2.3.2. Sprint Performance Measurement

After the general 15-min warm-up (10 min running, and 5 min of whole-body dynamic mobility exercises) and an additional three repetitions of progressive acceleration from faster to sprint running, participants performed two 20 m sprints, with 3 min of rest between each exertion. Prior to testing, four photocell gates (Polifemo Radio Light, Microgate, Bolzano, Italy) were placed at the start, at 5 m, at 10 m, and at 20 m. The dominant foot (lead-off foot) [35] was placed one meter behind the first photocell. The time recording was automatically initialized when a participant crossed the first photocell gate and stopped when the participant crossed the last photocell gate at 20 m distance. Participants were instructed to sprint at least 25 m in order to reach the highest maximum sprinting speed. The fastest of the two split times on 5 m, 10 m, and 20 m distances was used in the final analysis [4]. All measurements were performed indoors.

2.3.3. Vertical Jump Performance Measurement

Vertical jump performance, measured as jump height (cm), was evaluated from the CMJ and SJ using an OptoJump infrared timing system (Microgate, Bolzano, Italy). The participants first performed three trials of CMJs followed by three trials of SJs [15]. One minute of rest was given between two trials. Prior to performing both jumps, participants were instructed about the jumping technique and later performed at least two submaximal familiarization repetitions of CMJs and SJs to learn proper jumping techniques [4]. The CMJ was performed by flexing the knee to a squat position (approximately 90° of knee flexion) from an upright position and then immediately extending the hips and the knee into a vertical jump, whereas the SJ was performed by jumping to vertical from squat position (90° of knee flexion) [20]. When approaching the landing position, participants were advised to land with extended knees to avoid any measurement error resulting from prolonged flight time. Both jumps were performed with hands placed on hips and with legs straightened during the flight. The jump height was calculated from the recorded flight time ($\text{height} = [\text{gravitational acceleration (9.81 m/s}^2) \times \text{flight time}^2] \times 8 - 1$) [4], and the highest jump was used in the final analysis.

2.3.4. Handball Shooting Performance Measurement

Handball shooting performance was evaluated by measuring the ball velocity of a three-step set shot from the ground and the ball velocity of a three-step jump shot from the 9-m line, using the Bushnell Radar (Bushnell, Overland Park, KS, USA) with a measurement error of ± 1.60 km/h (www.bushnellsspeedster.com). The investigator measured ball velocity while standing at the 9-m line within 1 m of the participant performing the throw. After the warm-up, each participant performed one familiarization shot and two test shots of each shot type, with one minute of rest between shots [14,15].

2.3.5. Maximal Isokinetic Strength Measurement

Isokinetic concentric torque of knee extensors and flexors was measured using an isokinetic dynamometer Biodex Pro 4 (Biodex Medical Systems, Shirley, New York, NY, USA) at 60°/s and 180°/s according to previous guidelines and studies [18,36]. Prior to testing day, the machine was calibrated according to manufacturer guidelines, using a long shoulder attached to the axis of the apparatus, generating a standard torque of 67.8 Nm.

Prior to testing, each participant completed a standardized warm-up protocol consisting of 10 min of light jogging, followed by short dynamic stretching exercises for lower limbs, and ending with a single 8-repetition set of squat and hip thrust exercises. After the general warm-up, the participants were seated upright in the dynamometer chair with restraining belts fastened across the chest, pelvis, and leg thigh to minimize body movement or any potential compensation of synergist muscles. Later, we aligned the dynamometer axis of rotation to the participant's knee joint axis of rotation using the lateral epicondyle as the anatomic mark. Additionally, gravitation torque error was measured prior to each trial, and the starting leg was randomly selected for each participant. The range of motion was set at 80°, from 90° to 10° of knee flexion.

Prior to measuring maximal effort, each participant first performed a specific warm-up on the dynamometer consisting of 10 submaximal concentric contractions of knee flexion and extension at 60°/s. The maximal test was conducted after 2 min of rest, with participants performing five maximal concentric knee extensions and flexions. Verbal encouragement was given by the investigator during the test to ensure participants performed at their maximal effort. The maximal value out of five measurements was normalized to body weight (N/kg) and used in the final statistical analysis. In addition, bilateral differences between left and right maximal isometric torque (left leg/right leg maximal isometric torque × 100%) and unilateral hamstring-to-quadriceps maximal isometric torque (hamstring/quadriceps maximal isometric torque × 100%) [37] was calculated prior to further statistical analysis.

2.4. Statistical Analysis

Categorical variables are presented as frequencies and percentages, and numeric variables are presented as means and standard deviations, unless otherwise stated. All numeric variables were firstly screened for assumptions of normality of distribution and homogeneity of variances using the Shapiro–Wilk test and the Levene's test, respectively. This was screened for the whole sample and according to each playing position. The difference between playing positions was calculated using one-way analysis of variance (ANOVA) for normally distributed variables and homogeneous variances, otherwise, the Kruskal–Wallis test was applied. When one-way ANOVA detected significant differences between playing positions, an additional post hoc analysis was performed using the Tukey's honest significance test or pairwise comparisons, depending on the dispersion of variances between playing positions. Correlations between anthropometric, physical, and handball performance were assessed using Spearman's rank correlation coefficient. All statistical analyses were performed using IBM SPSS version 21 (SPSS Inc., Armonk, New York, NY, USA), and the level of significance was set at p -value < 0.05.

3. Results

There were statistically significant differences for playing positions in all measured anthropometric characteristics and skeletal muscle mass and fat mass (all p -values < 0.01; Table 1). The wings were significantly shorter compared to backcourt players ($p < 0.001$), pivots ($p = 0.035$), and goalkeepers ($p = 0.018$). Similar significant differences were obtained in weight (pivots vs. wing, $p < 0.001$; wings vs. backcourt players, $p < 0.001$), wingspan (wings vs. pivots, $p < 0.001$; wings vs. backcourt players, $p < 0.001$; wings vs. goalkeepers, $p = 0.038$), and thigh circumference (wings vs. pivots, $p < 0.001$; wings vs. backcourt players, $p = 0.041$). Additionally, pivots were heavier than goalkeepers ($p < 0.001$) and backcourt players ($p = 0.003$) and had larger thigh circumference compared to goalkeepers ($p < 0.001$) and backcourt players ($p < 0.001$), whereas backcourt players were heavier than goalkeepers ($p = 0.015$).

Table 1. Differences between playing positions in anthropometric characteristics and body composition.

	Backcourt Player (N = 34)	Wing (N = 26)	Pivot (N = 15)	Goalkeeper (N = 17)	<i>p</i>
Height (cm)	187 (8) ¹	179 (7)	185 (7) ¹	185 (6) ¹	<0.001
Weight (kg)	87 (11) ^{1,2}	75 (9)	102 (11) ^{1,2}	78 (10)	<0.001
Wingspan (cm)	190 (9) ¹	180 (8)	191 (9) ¹	186 (8) ¹	<0.001
Thigh circ. (cm)	60 (5) ¹	57 (5)	68 (5) ^{1,2,3}	58 (5)	<0.001
Skeletal muscle mass (kg)	44 (5) ^{1,2}	38 (4)	47 (5) ^{1,2}	37 (4)	<0.001
Body fat mass (kg)	12 (5)	10 (4)	23 (8) ^{1,2,3}	15 (7) ¹	<0.001

Cir.—circumference, ¹—significantly different from the wing, ²—significantly different from the goalkeeper, ³—significantly different from backcourt players.

Body composition measurements revealed that goalkeepers had significantly less skeletal muscle mass than backcourt players ($p < 0.001$) and pivots ($p < 0.001$), while wings had less skeletal muscle mass than backcourt players ($p < 0.001$) and pivots ($p < 0.001$). Pivots, on the other hand, had significantly more fat mass than wings ($p < 0.001$), backcourt players ($p < 0.001$) and goalkeepers ($p = 0.005$). Lastly, goalkeepers also had significantly more muscle mass than wings ($p = 0.010$).

Similar to the anthropometric characteristics, the playing positions differed in maximal isokinetic concentric extensor strength at 60°/s and 180°/s ($p < 0.001$), concentric knee flexion of the left knee at 60°/s ($p = 0.007$), and borderline significance of the right knee ($p = 0.070$) (Table 2). Pivot players displayed lower isokinetic concentric torque of knee extensors and flexors compared with wings and backcourt players at 60°/s and 180°/s, respectively, whereas backcourt players were superior compared to goalkeepers at 60°/s and 180°/s of knee flexion and extension. Additionally, wings performed better than goalkeepers at 60°/s and 180°/s of knee extension and flexion. Otherwise, no differences between playing positions were obtained in hamstring-to-quadriceps ratio (HQR) and in bilateral differences in maximal concentric torque of extensors and flexors at 60°/s and 180°/s.

Table 2. Differences among playing positions in isokinetic concentric torque.

	Backcourt Player (N = 34)	Wing (N = 26)	Pivot (N = 15)	Goalkeeper (N = 17)	<i>p</i>
Extension left knee at 60°/s (Nm/kg)	2.80 (0.58)	2.88 (0.55)	2.23 (0.45) ^{1,2}	2.53 (0.32) ^{1,2}	<0.001
Extension right knee at 60°/s (Nm/kg)	2.86 (0.45)	2.83 (0.56)	2.30 (0.43) ^{1,2}	2.50 (0.35) ²	<0.001
Extension left knee at 180°/s (Nm/kg)	1.80 (0.32)	1.85 (0.28)	1.42 (0.28) ^{1,2}	1.49 (0.29) ^{1,2}	<0.001
Extension right knee at 180°/s (Nm/kg)	1.79 (0.27)	1.73 (0.36)	1.45 (0.27) ^{1,2}	1.51 (0.24) ²	<0.001
Flexion left knee at 60°/s (Nm/kg)	1.74 (0.38)	1.74 (0.38)	1.50 (0.63) ^{1,2}	1.52 (0.24) ^{1,2}	0.007
Flexion right knee at 60°/s (Nm/kg)	1.78 (0.25)	1.70 (0.39)	1.57 (0.59)	1.53 (0.39)	0.070
Flexion left knee at 180°/s (Nm/kg)	1.33 (0.29)	1.33 (0.30)	1.07 (0.34) ^{1,2}	1.11 (0.26) ^{1,2}	0.002
Flexion right knee at 180°/s (Nm/kg)	1.32 (0.25)	1.21 (0.28)	1.08 (0.34) ²	1.12 (0.22) ²	0.012
Bilateral ratio left–right knee extension at 60°/s (%)	98.23 (15.08)	102.36 (9.97)	95.95 (7.04)	96.95 (7.04)	0.251
Bilateral ratio left–right knee flexion at 60°/s (%)	98.50 (21.14)	103.16 (11.35)	95.17 (10.47)	102.86 (20.42)	0.059
Bilateral ratio left–right knee extension at 180°/s (%)	101.89 (19.47)	110.65 (16.02)	100.71 (13.56)	98.58 (11.86)	0.112
Bilateral ratio left–right knee flexion at 180°/s (%)	101.43 (17.55)	109.70 (19.37)	97.76 (9.74)	98.59 (13.11)	0.068
HQR left knee at 60°/s (%)	63.23 (17.97)	60.84 (11.78)	70.29 (36.66)	59.93 (6.39)	0.725
HQR right knee at 60°/s (%)	63.56 (12.52)	60.54 (11.69)	69.40 (28.23)	61.06 (12.21)	0.958
HQR left knee at 180°/s (%)	74.18 (15.22)	71.55 (11.83)	77.35 (27.68)	74.67 (13.42)	0.596
HQR right knee at 180°/s (%)	74.32 (14.73)	70.90 (12.91)	74.58 (21.80)	74.17 (10.87)	0.704

HQR—hamstring-to-quadriceps torque ratio, ¹—significantly different from the wing, ²—significantly different from backcourt players.

Measurements of sprinting and vertical jump performance showed significant differences between playing positions (all p -values < 0.01 ; Table 3). Wing players were significantly faster than backcourt players (5 m, $p = 0.042$; 10 m, $p = 0.001$; and 20 m, $p = 0.027$), goalkeepers (5 m, $p = 0.013$; 10 m, $p = 0.001$; and 20 m, $p = 0.001$), and pivots (5 m, $p = 0.001$ and 20 m, $p < 0.001$). At the 10-m time gate, backcourt

players were significantly faster than goalkeepers ($p < 0.001$). Moreover, backcourt players and wings jumped significantly higher compared to pivots (backcourt players vs. pivots: CMJ, $p = 0.007$, SJ, $p = 0.027$; wings vs. pivots: CMJ, $p < 0.001$, SJ, $p < 0.001$) and goalkeepers (backcourt players vs. pivots: CMJ, $p = 0.006$; wings vs. goalkeepers: CMJ, $p < 0.001$, SJ, $p = 0.004$), respectively.

Table 3. Differences between playing positions in sprinting, vertical jump performance, and handball shooting performance.

	Backcourt Player (N = 34)	Wing (N = 26)	Pivot (N = 15)	Goalkeeper (N = 17)	<i>p</i>
Sprint 5 m (s)	1.05 (0.08) ¹	1.01 (0.08)	1.11 (0.09) ¹	1.10 (0.12) ¹	0.006
Sprint 10 m (s)	1.83 (0.20) ¹	1.75 (0.24)	1.93 (0.30)	1.97 (0.13) ^{1,3}	0.003
Sprint 20 m (s)	3.31 (0.24) ¹	3.15 (0.19)	3.44 (0.22) ¹	3.42 (0.17) ¹	<0.001
SJ (cm)	30 (5)	32 (6)	25 (6) ^{1,3}	26 (4) ^{1,3}	<0.001
CMJ (cm)	34 (4)	37 (6)	29 (6) ^{1,3}	31 (5) ¹	<0.001
Set shot (km/h)	89 (7) ^{1,2}	84 (9) ²	89 (5) ²	79 (6)	<0.001
Jump shot (km/h)	88 (7) ^{1,2}	83 (9) ²	87 (9) ²	77 (6)	<0.001

SJ—squat jump, CMJ—countermovement jump, ¹—significantly different from the wing, ²—significantly different from the goalkeeper, ³—significantly different from backcourt players.

There were also significant differences in ball velocity among playing positions (both p -values <0.001). Post hoc analysis showed that goalkeepers shoot the ball at significantly lower velocity while shooting from ground position (all p -values < 0.01) or while performing a three-step jump shot (all p -values < 0.01).

Correlations between handball shooting performance and sprinting, jumping, and maximal strength performance are shown in Table 4. With the exception of body fat mass and thigh circumference, all other anthropometric characteristics were significantly correlated with the ball velocity of a three-step set shot and jump shot. A higher SJ was significantly correlated with the ball velocity of the set shot, and borderline significant with the ball velocity of the jump shot. Maximal isokinetic torque of knee flexors and extensors was significantly correlated with ball velocity of both shot types. Lastly, HQR at 60°/s was significantly correlated with the ball velocity of the set shot.

Table 4. Correlations between playing positions in sprinting, vertical jump performance, and handball shooting performance.

	Set Shot (m/s)		Jump Shot (m/s)	
	Spearman Rho	<i>p</i>	Spearman Rho	<i>p</i>
Height (cm)	0.330	0.001	0.263	0.011
Weight (kg)	0.303	0.003	0.282	0.006
Skeletal muscle mass (kg)	0.522	<0.001	0.473	<0.001
Body fat mass (kg)	−0.116	0.267	−0.083	0.428
Wingspan (cm)	0.387	<0.001	0.349	0.001
Thigh circumference (cm)	0.183	0.080	0.166	0.112
Sprint 20 (s)	0.061	0.566	−0.018	0.862
SJ (cm)	0.210	0.043	0.185	0.076
CMJ (cm)	0.128	0.221	0.057	0.585
Knee extension torque at 60°/s (Nm)	0.219	0.035	0.340	0.001
Knee extension torque at 180°/s (Nm)	0.352	0.001	0.419	<0.001
Knee flexion torque at 60°/s (Nm)	0.493	<0.001	0.465	<0.001
Knee flexion torque at 180°/s (Nm)	0.477	<0.001	0.460	<0.001
HQR at 60°/s (%)	0.317	0.002	0.171	0.101
HQR at 180°/s (%)	0.139	0.185	0.061	0.564

SJ—squat jump, CMJ—countermovement jump, HQR—hamstring-to-quadriceps torque ratio.

4. Discussion

In the present study, we identified differences between playing positions in anthropometric characteristics, isometric maximal leg strength, sprinting and vertical jumping performance, and established new evidence on the relationship between anthropometry, physical performance, and ball velocity as an indicator of game performance. The most novel findings of this study were related to isokinetic performance, adding to the few reports of the isokinetic maximal strength and strength imbalances in elite male handball players that have been published to our knowledge [19–21]. Our results suggest that maximal knee flexor and extensor strength is related to playing position, whereas no differences between playing positions were observed in bilateral muscle imbalances or the ratios between knee joint agonists and antagonists.

In the previous studies of sports performance in elite handball, the investigators applied different methods to assess maximal leg strength. Most of those studies on elite male handball players used different variations of maximal squat tests to determine maximal leg strength [4,11,15,32], while (only) a small body of evidence used isokinetic testing [19,20], despite it being considered the gold standard for assessing quadriceps and hamstring maximal strength and muscle imbalances [17,18]. Most studies measuring maximal isokinetic knee strength were performed with females [18,24,38,39], likely due to higher rates of anterior cruciate ligament injuries, compared with males [40], while only two isokinetic studies included male handball players [19,20]. In the latter studies, male handball players were recognized as functionally balanced athletes, where maximal unilateral (50–69%) and bilateral (10–15%) muscle strength differences were in the normal range [19,20]. This was similarly demonstrated in our study, although there were no bilateral differences in maximal strength of flexors and extensors, or muscle imbalances between hamstrings and quadriceps on each leg at 60°/s and 180°/s. Our relative values of maximal flexion and extension torque at 60°/s and 180°/s (N/kg) were also similar to a report by Gonzalez-Rave et al. [20]. Additionally, our study also evaluated the difference between playing positions in relative maximal strength and muscle imbalances. Backcourt and wing players were the strongest in extension and flexion, independent of muscle mass at both angular velocities. These results may potentially be associated with game demands, as wings and backcourt players perform the most jumps and throws [7]. In contrast, all playing positions showed symmetrical strength (unilateral and bilateral ratios in the normal range) between legs and within each leg analysis.

Studies have suggested that anthropometric characteristics are related to playing position. In our study, wing players were the shortest, had the lowest body weight, shortest wingspan and smallest thigh circumference, while pivots had the highest body weight, skeletal muscle mass, and body fat mass content. These results were in line with previous studies [7,10,13–16] from elite and sub-elite male handball players. Despite the similar ages of players and the differences between playing positions in body weight and height, our subsample of backcourt players, pivots, and goalkeepers was generally shorter and lighter than players competing on elite German [10,14], Norwegian [15], and national teams playing in the World Championship [9]. Thus, these differences can be explained by the level of play and age. Players competing in lower leagues were generally shorter [10], independent of playing position, whereas pivots in higher leagues were heavier and had the highest body mass index [14]. Also, younger elite handball players were shorter, lighter, had lower free fat mass and body mass index values compared to elite adult players [16].

The fastest sprint times were recorded in wing players compared to other playing positions on each of three time gates (5 m, 10 m, and 20 m). Similar variations in sprinting performance at 20 m were observed in the other two studies consisting of handball players performing in elite European leagues [14,15]. In addition to the fastest times recorded by wings, backcourt players were also faster than goalkeepers on 10-m sprints, similar to data obtained by Haugen et al. [15] (wings, 2.78 (0.08) s; backcourt players, 2.83 (0.11) s; goalkeepers, 2.94 (0.10) s). Partly contrary to our findings, one study reported significant differences between playing positions only on longer sprint distances (30 m), postulating equal starting acceleration of all playing positions, which likely contributed to the longer competitive career and a higher level of competition [14]. Moreover, sprinting performance is closely

related to the in-game demands of each playing position. Data derived from game movement analysis has shown that wing players have a higher frequency of performed sprints, with the longest duration, time, and fraction of distance covered compared to pivots and backcourt players [7].

Vertical jumping is an important movement performed during the course of the game [7]. In previous studies, the best vertical jumps were performed by the wings (39–50 cm) and backcourt players (38–47 cm), compared to pivots (35–43 cm) and goalkeepers (35–47 cm) [14,15]. Similar differences between playing positions were also obtained in our study. Nevertheless, jump performance was lower compared to data from two samples of elite European Championship players [14,15], but comparable to a similar level of play [16], thus, our results were likely influenced by the level of play and quality of the training regime.

Handball scoring efficiency is largely dependent on ball velocity. In our study, ball velocity was highest in backcourt players and lowest in wings and goalkeepers. A similar superiority was also obtained in other samples of elite players [13–15], although the maximal shooting velocities of our participants (88.94 km/h) were only comparable to one study (90.72 km/h) [14], while others performed better (94.32–96.84 km/h) [13,15]. The best shooting performance from three-step shots was reported in a sample of Tunisian national team players (99.67 km/h), although it showed no significant difference between playing positions, likely due to its small sample size ($N = 21$) [11].

The kinematics of overhead shoots is a highly complex whole-body movement [26], with many studies undertaken to identify the possible determinants of shooting success [10,11,13,31,32]. Our results supported previous findings that suggest body height and mass may influence shooting velocities from a standing [11] and/or jumping position [10,13,31]. In contrast, several studies investigating the correlations between physical performance and ball velocity have been inconclusive [11,13,31,32]. Others, including our study, reported significant correlations between ball velocity and sprinting time, lower limb maximal strength, and endurance [31,32], while others failed to reach such conclusions [11,13]. Furthermore, our results also highlighted the importance of lower limb muscle mass and strength as an initiator of proximal-to-distal principal during the shot [41]. When an optimal sequence of force translation from proximal muscles of legs, pelvis, and trunk to throwing arm is achieved, the highest force production in the leg muscles can substantially contribute to higher ball velocities [27,29,32], as confirmed in our study. Similarly, recent study has suggested that jump height in the CMJ is significantly correlated with jump height while performing a jump shot in a game-based performance test [42]. During the handball game, this may present an advantage over the opponent, as the three-step jump shot is the most frequently executed shot [26]. In addition to faster ball-shooting velocity, the importance of jump height may also explain the higher frequency of jumps and shots performed during the game by backcourt players compared to pivots and goalkeepers [7]. However, as a handball shot is a complex, multi-joint movement, more research is needed to determine new potential physical performance determinants of shooting success (e.g., ball velocity).

In summary, the results of this study may further clarify several important aspects of the anthropometric and physical aspects of handball performance with special reference to playing position. Firstly, we confirmed previously reported variations between playing positions in anthropometric characteristics, sprinting, jumping, and handball shooting performance. Secondly, and most importantly, our study was one of the first to establish new evidence on the isokinetic maximal strength of lower limbs. We provided novel data for maximal torque of extensors and flexors in elite handball as well as demonstrated that male handball players are symmetrical with no significant maximal strength deficits between, and within, knee extensors and flexors. Lastly, our study also established further evidence on the potential role of various physical performance aspects in handball success as measured by ball velocity. Despite presenting novel findings on one of the largest samples in male handball performance research, some limitations must be acknowledged. Most of our sample were members of Kosovo's national handball team, but none of them played abroad in higher-ranking leagues or the European Championship league. As Kosovo is a young country with very few professional handball opportunities, our results may be affected by the playing level, training process, and relative

lack of experience of the players. Nevertheless, our data showed results comparable to other elite playing countries, e.g., Germany and Norway, therefore, we believe that strong professional handball foundations have been built in Kosovo.

5. Conclusions

In conclusion, our study clearly demonstrated the importance of anthropometry, jumping performance, and maximal isometric strength to handball performance. In future sports practice, more emphasis should be given to handball-specific resistance training for players to gain more muscle mass of lower (legs and pelvis) and upper limbs (shoulders and arms), which will afterwards manifest in better jumping, sprinting, and shooting performance. Special consideration must be given to resistance training of pivots and goalkeepers to improve their muscle strength and shooting performance [2], as they were outperformed by wings and backcourt players. Furthermore, we also propose the routine inclusion of isometric measurement of shoulder and knee joint maximal torques to monitor changes of maximal muscle strength during the course of the handball season and to detect potential muscle imbalances, which may contribute to higher injury incidence. In line with this, more studies on elite and sub-elite handball players should be conducted to provide new practical evidence of the importance of isokinetic testing and to further determine several important aspects of physical performance in relation to handball shooting performance.

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