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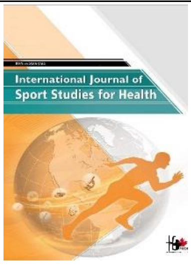

Handball Performance Optimization: Anthropometric and Physical Factors Related with Shoot Speed

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A B S T R A C T

Objective: Handball is a high-intensity, strategic sport requiring strength, speed, and agility, with throwing speed being a key component of offensive performance. This study aimed to analyze the relationship between ball throwing speed and anthropometric variables, body composition, and hand grip strength in male and female handball players across three age categories: U-16, U-18, and U-21.
Methods and Materials: A total of 226 players (109 males, 117 females) from four Mexican regions were assessed using a cross-sectional, descriptive-correlational design. Anthropometric measurements followed ISAK protocols, while body composition was assessed via bioelectrical impedance. Segmental lengths, grip strength, and throwing speed from 7 meters were also evaluated. Statistical analyses included ANOVA, t-tests, and stepwise linear regression. Results indicated age-related improvements in fat-free mass, grip strength, and throwing speed, particularly in U-21 players.
Findings: Males exhibited significantly greater height, lean mass, and performance metrics compared to females. Regression analysis revealed that total arm length and grip strength significantly predicted throwing speed in males, while grip strength, fat percentage (negative), and BMI were significant predictors for females. Age-stratified analyses highlighted that total arm length predicted speed in U-16 males, body weight in U-18 males, and grip strength in U-21 athletes of both sexes.
Conclusion: These findings underscore the importance of strength and specific anthropometric traits in throwing performance and suggest the need for age- and sex-specific training strategies to optimize development. The study supports incorporating tailored conditioning programs to enhance handball players' throwing ability based on developmental and physical profiles.
Keywords: *throwing speed, handball players, anthropometric characteristics, body composition, hand grip strength*.

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1. Introduction

Handball is a high-intensity sport that demands both physical and tactical commitment from athletes. It is played in over 180 countries, with approximately 19 million registered players worldwide. The game is characterized by the integration of strength, speed, and strategy, involving frequent high-intensity actions such as jumping, changing direction, and shooting (1, 2). Given the importance of these actions for handball performance, muscle strength development has been identified as a key factor in optimizing players' performance (1, 3). Strength enhances the execution of technical elements, such as goal throws, which are fundamental in handball. In this context, the goal throw is considered a primary skill, with ball speed playing a crucial role in maximizing the efficiency of offensive plays (4).

Numerous studies have analyzed the factors influencing goal throw speed, emphasizing maximum dynamic force, body composition, and various anthropometric measures (3, 5, 6). Key attributes such as height, arm span, and hand dimensions have also been highlighted (7-9). Additionally, total arm length has been linked to increased shot-to-goal speed (10, 11). However, the relationship between the body composition, anthropometric, hand grip strength and throw speed variables remains inconsistent in the literature, indicating the need to account for factors such as age, sex, and playing position (1, 12) to draw more definitive conclusions.

Literature has supported the influence of body composition on goal throw speed, indicating that bone density and mineral content have a greater impact on this variable than lean or fat mass (13, 14). However, Canlı (1) reported that fat mass percentage (%FM), body mass index (BMI), manual grip strength, and anthropometric measures such as sitting height and arm span showed no significant correlation with goal throw speed. The lack of consensus in the literature highlights the need for further research examining the interaction between these variables within specific contexts, such as age category, sex, and experience level (2).

In addition to the factors mentioned above, manual grip strength has been investigated as a potential indicator of throw-to-goal performance, showing a moderated relationship with shot speed. This relationship may vary depending on factors such as the type of throw and the sex of the players (15, 16). However, hand grip strength alone does not appear to fully account for differences in shot speed or overall throw-to-goal performance, especially when technical and methodological factors, as well as competition level, are considered (17). Given the current evidence that shows mixed results, it is essential to conduct further studies that comprehensively analyze shot speed, anthropometric characteristics, body composition, and hand grip strength. These studies should also account for variables such as sex and age category in order to provide a more holistic understanding of handball performance in youth players.

To address the problem outlined above, the present study aimed to analyze the association between shot speed and anthropometric measures, body composition, and hand grip strength in U-16, U-18, and U-21 male and female handball players. Based on existing literature, the authors hypothesized that shot speed would be positively correlated with hand grip strength and certain anthropometric variables such as height, arm span, and body composition indicators, particularly a higher lean mass, and free fat mass (FFM). It was further expected that these correlations would vary according to sex and age category (U-16, U-18, and U-21), due to differences in physical development and training experience.

2. Methods and Materials

2.1 Study Design and Participants

A cross-sectional, descriptive-correlational study was conducted on handball players from four different regions of Mexico. Study sample composed by 109 men (age = 17.4 ± 3.4 years; weight = 71.3 ± 13.9 kg; height = 173.5 ± 6.0 cm) and 117 women (age = 16.8 ± 1.9 years; weight = 63.0 ± 11.7 kg; height = 161.9 ± 6.4 cm), divided according to their age category: U-16, U-18, U-21. To participate in the study, athletes were required to meet the following inclusion criteria: i) be members of the state-level handball team competing in the tournament; ii) be in optimal physical condition to perform the shooting evaluation protocol; and iii) provide signed informed consent or assent for participation. Athletes presenting any type of injury were excluded from the study.

2.2 Procedure

Prior to an official competition, various measurements were taken, including height, weight, lean mass, fat mass percentage, and free fat mass, as well as body segment lengths, handgrip strength, and shooting speed from seven meters. Anthropometric assessments were carried out by a certified ISAK (International Society for the Advancement of Kinanthropometry) practitioner (RGL), following the standardized protocols outlined by Esparza-Ros et al. (18).

The research protocol was registered with the Facultad de Organización Deportiva at the Universidad Autónoma de Nuevo León. Prior to the evaluation, all participants signed an informed consent form, which provided a detailed explanation of the study procedures, and the potential risks involved. For underage athletes, informed consent was obtained from their parents or legal guardians, and informed assent was signed by the athletes themselves. At the time of assessment, all participants were in optimal physical condition and reported no injuries. The measurements were supervised by coaches and trained assistant personnel. Throughout the study, researchers ensured the integrity and anonymity of all participants, in full compliance with the Declaration of Helsinki guidelines (19), as well as the ethical and procedural recommendations for research in sports medicine and exercise science (20).

2.3 Measures

Anthropometric Measurements: Height was measured using a Seca 225 stadiometer (accuracy ±5 mm), while weight, body mass index (BMI), lean mass, and body fat percentage were assessed through bioelectrical impedance analysis with a TANITA TBF-410 monitor (Tanita Corporation, Tokyo, Japan). Segmental lengths of the upper limb were measured using a Rosscraft segmometer, including the acromiale–radiale, radiale–stylion, and medial stylion–dactylion segments. The sum of these three measurements represented the total upper limb length. Additionally, the hand span was measured horizontally, from the tip of the thumb to the tip of the little finger. Furthermore, sitting height were recorded while participants were seated on an anthropometric bench. Lower limb length was calculated by subtracting sitting height from total body height.

Hand Grip Strength: Upper limb isometric strength was assessed using a GRIP-D digital dynamometer (accuracy ±0.5 kg). A standardized protocol was followed, consisting of three trials for each limb (right and left), with the highest value from each side selected for analysis (21, 22).

Throwing Speed: Participants completed a standardized 10-minute warm-up on an indoor handball court. Following the warm-up, they were instructed to perform throws toward the center of a standard goal using Molten handballs appropriate to their category: size 2 (330–375 g; 54–56 cm) for all female athletes and U16 males, and size 3 (425–475 g; 58–60 cm) for U18 and U21 males. Each throw was executed from the 7-meter line, with the requirement that at least one foot remained in contact with the ground during the throw (simulating a seven-meter handball throw). Each participant performed three attempts, with a 30-second rest interval between throws. Only throws that successfully entered the goal were considered valid. Ball velocity was measured using a Stalker Pro-2 radar gun (Applied Concepts, Texas, USA), following the standardized protocols described in previous research (23).

2.4 Data Analysis

Data analysis was conducted using IBM SPSS Statistics software, version 23 for Windows. Descriptive statistics (mean and standard deviation) were calculated for all variables, including segmental lengths, body composition, handgrip strength, and throwing speed. The normality of the data distributions was assessed using both visual inspection (histograms and Q-Q plots) and the Kolmogorov–Smirnov test showing a p-value > .05.

Group differences among age categories (U16, U18, and U21) were analyzed using one-way analysis of variance (ANOVA), followed by Tukey’s post hoc test for multiple comparisons ($p < 0.05$). Sex differences were evaluated using independent samples t-tests. To examine the relationship between throwing velocity and anthropometric variables, body composition, and handgrip strength, a forward stepwise multiple regression analysis was performed, after confirming that the assumptions for this statistical method were met.

3. Results

Table 1 presents the significant differences among the U-16, U-18, and U-21 male categories across the analyzed variables. As expected, age showed significant differences ($p < .001$, $\eta^2 = 0.734$), while height did not vary significantly between groups ($p = .358$). In terms of body composition, weight ($p = .020$, $\eta^2 = 0.071$), BMI ($p = .020$, $\eta^2 = 0.072$), and free fat mass ($p < .001$, $\eta^2 = 0.269$) increased with age, with U-21 players exhibiting the highest body weight. Conversely, fat percentage ($p < .001$, $\eta^2 = 0.212$) and fat mass ($p = .035$, $\eta^2 = 0.061$) decreased with age, with the U-21 category showing the lowest values, indicating an overall improvement in body composition. No significant differences were observed in lengths and heights or physical performance tests; however, hand grip strength showed a tendency to increase with age.

Table 1. Differences among U-16, U-18, and U-21 male categories across all observed variables

Measures	U-16 [a] (n = 45) M ± SD	U-18 [b] (n = 33) M ± SD	U-21 [c] (n = 31) M ± SD	*F*	*p*	η²
Basic measures						
Age (years)	15.20 ± 0.69 b, c	16.90 ± 0.84 a, c	19.51 ± 1.63 a, b	146.569	< .001	0.734
Heigh (cm)	172.3 ± 5.96	174.0 ± 6.72	174.0 ± 5.32	1.037	.358	0.019
Body composition						
Weight (kg)	67.5 ± 13.78 c	69.88±14.22	76.16±11.01 a	4.038	.020	0.071
BMI (kg/m2)	22.65 ± 4.08 c	23.32 ± 3.64	25.12 ± 3.31 a	4.038	.020	0.072
Fat (%)	22.15 ± 6.01 c	21.04 ± 6.56 c	15.71 ± 4.42 a,b	14.3	< .001	0.212
Fat mass (kg)	15.47 ± 6.74 c	15.14 ± 5.98	12.58 ± 5.21 a	3.469	.035	0.061
FFM (kg)	52.02 ± 8.58 c	55.65 ± 9.36 c	64.19 ± 6.94 a, b	19.507	< .001	0.269
Lengths and heights						
Sitting height (cm)	90.45 ± 3.60	91.30 ± 2.98	91.74 ± 2.55	1.661	.195	0.03
Lower limb length (cm)	81.89 ± 3.65	82.72 ± 4.87	82.31 ± 3.86	0.384	.682	0.007
Total arm length(cm)	78.36 ± 3.43	79.41 ± 3.70	79.09 ± 3.05	0.987	.376	0.018
Acromiale-radiale (cm)	32.76 ± 1.72	32.99 ± 1.74	33.19 ± 1.74	0.574	.565	0.011
Radiale-stylion (cm)	26.42 ± 1.26	27.00 ± 1.40	26.76 ± 1.15	1.974	.144	0.036
Midstylion-dactylion (cm)	19.16 ± 0.97	19.42 ± 1.18	19.13 ± 0.69	0.864	.425	0.016
Hand span (cm)	21.85 ± 1.33	22.30 ± 1.27	21.69 ± 1.05	2.288	.107	0.042
Physical test						
Grip strength (kg)	34.04 ± 7.53	36.43 ± 7.20	37.81 ± 5.63	2.852	.062	0.052
Speed shoot (km/h)	69.47 ± 8.56	68.98 ± 7.07	68.55 ± 9.45	0.113	.893	0.002

Note: BMI = Body Mass Index; FFM = Free Fat Mass; M = Mean; SD = Standard deviation; a = Significant difference to U-16 ($p < 0.05$); b = Significant difference to U-18 ($p < 0.05$); c = Significant difference to U-21 ($p < 0.05$).

Regarding female participants, Table 2 shows that age differed significantly between groups, as expected ($p < .001$, $\eta^2 = 0.724$). Height demonstrated an increasing trend in the U-21 group ($p = 0.052$). In terms of body composition, fat percentage was significantly lower in U-21 athletes compared to U-16 and U-18 ($p = 0.002$, $\eta^2 = 0.103$), while fat-free mass significantly increased with age ($p < .001$, $\eta^2 = 0.277$). Bone length measurements revealed significant differences in sitting height ($p < .011$, $\eta^2 = 0.077$), midstylion-dactylion ($p < .001$, $\eta^2 = 0.175$), and hand span ($p < .001$, $\eta^2 = 0.137$), all of which were greater in the U-21 group. Finally, the physical performance tests showed significant improvements in grip strength ($p = .007$, $\eta^2 = 0.084$) and ball throwing speed ($p < .001$, $\eta^2 = 0.168$) in the U-21 category compared to the younger groups.

Table 2. Differences among U-16, U-18, and U-21 female categories across all observed variables

Measures	U-16 [a] (n = 45) M ± SD	U-18 [b] (n = 33) M ± SD	U-21 [c] (n = 31) M ± SD	*F*	*p*	η²
Basic measures						
Age (years)	15.10 ± 0.09	17.17 ± 0.56	20.15 ± 2.22	149.507	< .001	0.724
Heigh (cm)	161.7 ± 6.31	160.4 ± 5.93 c	164.0 ± 6.59 b	3.034	.052	0.051
Body composition						
Weight (kg)	61.67 ± 10.90	62.00 ± 9.88 c	67.86±13.77 b	3.03	.052	0.051
BMI (kg/m2)	23.60 ± 4.04	24.10 ± 3.62	25.18 ± 4.56	1.491	.230	0.025
Fat (%)	31.92 ± 8.21 c	29.64 ± 7.12	26.10 ± 5.13 a	6.556	.002	0.103
Fat mass (kg)	20.37 ± 8.49	19.92 ± 7.12	18.25 ± 7.08	0.774	.464	0.013
FFM (kg)	41.32 ± 4.68 c	43.06 ± 5.21 c	49.61 ± 7.35 a,b	21.799	< .001	0.277
Lengths and heights						
Sitting height (cm)	86.11 ± 3.07	85.42 ± 3.12 c	87.78 ± 3.68 b	4.728	.011	0.077
Lower limb length (cm)	75.70 ± 3.77	75.00 ± 3.46	76.30 ± 4.94	0.869	.422	0.015
Total arm length(cm)	72.94 ± 2.97	72.51 ± 2.93	74.14 ± 2.91	1.527	.222	0.026
Acromiale-radiale (cm)	30.40 ± 1.50	30.23 ± 1.67	30.84 ± 1.28	2.819	.064	0.047
Radiale-stylion (cm)	24.80 ± 1.11	24.76 ± 1.08	24.92 ± 1.22	0.195	.823	0.003
Midstylion-dactylion (cm)	17.71 ± 0.80 c	17.51 ± 0.60 c	18.37 ± 0.81 a,b	12.112	< .001	0.175
Hand span (cm)	19.78 ± 1.08 c	19.71 ± 0.91 c	20.63 ± 0.96 a,b	9.058	< .001	0.137
Physical test						
Grip strength (kg)	22.65 ± 4.40 c	23.83 ± 4.24	25.96 ± 5.01 a	5.232	.007	0.084
Speed shoot (km/h)	53.83 ± 6.08 c	54.96 ± 5.11	60.30 ± 7.24 a	11.513	< .001	0.168

Note: BMI = Body Mass Index; FFM = Free Fat Mass; M = Mean; SD = Standard deviation; a = Significant difference to U-16 ($p < 0.05$); b = Significant difference to U-18 ($p < 0.05$); c = Significant difference to U-21 ($p < 0.05$).

Table 3 presents the differences between male and female participants across various measurements, with significant differences observed in nearly all variables. In the basic anthropometric data, age did not differ significantly between sexes (p = 0.509), while height was significantly greater in males than in females (p < .001, d = 1.83). Regarding body composition, males showed significantly higher body weight (p < .001, d = 0.57), lower fat percentage (p < .001, d = -1.39), and higher fat-free mass (p < .001, d = 1.49). No significant sex-based differences were observed in BMI (p = 0.23). In terms of lengths and heights, males significantly exceeded females in all measured segments—including trunk, leg, arm, humerus, radius, hand, and hand span —with effect sizes ranging from d = 1.44 to 1.79 (p < .001 for all). Finally, in physical performance tests, males also demonstrated superior results, showing significantly greater grip strength (p < .001, d = 2.00) and ball throwing speed (p < .001, d = 1.73).

Table 3. Descriptive data and the differences between men and women

Variable	*t*	*p*	*d*
Basic measures			
Age	-0.66	.509	-0.088
Heigh (cm)	13.77	< .001	1.83
Body composition			
Weight (kg)	4.25	< .001	0.57
BMI (kg/m2)	-1.2	.230	-0.16
Fat (%)	-10.49	< .001	-1.39
Fat mass (kg)	-5.65	< .001	-0.75
FFM (kg)	11.25	< .001	1.49
Lengths and heights			
Sitting height (cm)	10.79	< .001	1.44
Lower limb length (cm)	12.18	< .001	1.62
Total arm length(cm)	13.44	< .001	1.79
Acromiale-radiale (cm)	11.52	< .001	1.53
Radiale-stylion (cm)	11.61	< .001	1.55
Midstylion-dactylion (cm)	11.64	< .001	1.55
Hand span (cm)	12.78	< .001	1.7
Physical test			
Grip strength (kg)	15.01	< .001	2.00
Speed shoot (km/h)	13.00	< .001	1.73

Note: BMI = Body Mass Index; FFM = Free Fat Mass.

Table 4 presents the results of the stepwise linear regression analysis examining ball throwing speed in relation to various anthropometric and body composition variables in handball players, with separate models for males and females.

Table 4. Linear Regression Results

Men (n = 109)					Women (n = 117)				
Model	R^2	F	b	t	Model	R^2	F	b	t
M1	0.11	12.83*** (1,106)			M1	0.12	16.10*** (1,115)		
Total arm length			0.33	3.58***	Hand grip strength			0.35	4.01***
M2	0.15	8.88*** (2,105)			M2	0.17	11.82*** (2,114)		
Total arm length			0.23	2.23*	Hand grip strength			3.52	4.14***
Hand grip strength			0.22	2.13*	Fat (%)			-0.22	-2.6*
					M3	0.22	10.61*** (3,113)		
					Hand grip strength			0.3	3.55***
					Fat (%)			-0.44	-3.75***
					BMI			0.32	2.64*
U-16 men (n =)					U-16 women (n =)				
Model	R^2	F	b	t	Model	R^2	F	b	t
M1	0.11	6.53** (1,42)							
Total arm length			0.37	2.57**					
U-18 men (n =)					U-18 women (n =)				
Model	R^2	F	b	t	Model	R^2	F	b	t
M1	0.22	8.83** (1,31)							
Weight			0.47	2.97**					
U-21 men (n =)					U-21 women (n =)				
Model	R^2	F	b	t	Model	R^2	F	b	t
M1	0.18	6.14** (1,29)			M1	0.16	6.09** (1,31)		
Hand grip strength			0.42	2.48**	Hand grip strength			0.41	2.47**

Note: * $p < .05$, ** $p < .01$, *** $p < .001$

In the analysis for male players, total arm length (Model 1) was significantly associated with throwing speed (b = 0.33, t = 3.58, $p < 0.001$), accounting for 11% of the variance (R^2 = 0.11). When grip strength was added in Model 2, the explained variance increased to 15% (R^2 = 0.15). In this model, both total arm length (b = 0.23, t = 2.23, $p < 0.05$) and grip strength (b = 0.22, t = 2.13, $p < 0.05$) were significant predictors.

For female players, Model 1 identified grip strength as the only significant predictor of throwing speed (b = 0.35, t = 4.01, $p < 0.001$), explaining 12% of the variance (R^2 = 0.12). In Model 2, body fat percentage was added as a significant negative predictor (b = -0.22, t = -2.60, $p < 0.05$), increasing the explained variance to 17% (R^2 = 0.17). Finally, Model 3 incorporated body mass index (BMI) as a positive predictor (b = 0.32, t = 2.64, $p < 0.05$), resulting in a final R^2 of 0.22, explaining 22% of the variance in throwing speed.

When analyzing the results by age categories, significant associations were also observed within the U-16, U-18, and U-21 groups. In the U-16 group, total arm length emerged as a significant predictor of ball throwing speed in males only (b = 0.37, t = 2.57, $p < 0.01$).

In the U-18 group, body weight had a significant positive effect on throwing speed, again only in males (b = 0.47, t = 2.97, $p < 0.01$). For the U-21 category, grip strength was the primary predictor in both males (b = 0.42, t = 2.48, $p < 0.01$) and females (b = 0.41, t = 2.47, $p < 0.01$), highlighting its importance in older players regardless of sex.

4. Discussion and Conclusion

The primary objective of this study was to examine the relationship between throwing speed with anthropometric and body composition variables in handball players, with a focus on differences by sex and age category. The key findings confirm that total arm length and grip strength are significant predictors of throwing speed in male players. These results align with previous research emphasizing the role of these factors in generating force and efficiently transferring energy to the ball (9, 17). A longer arm provides a mechanical advantage through improved leverage, while greater grip strength enhances control and stability during the throwing motion—findings consistent with those reported by Zapartidis et al. (9) and Ortega-Becerra & Pareja-Blanco (17).

Among female players, grip strength also emerged as a significant predictor. However, body fat percentage had a negative effect on throwing speed, underlining the importance of lean mass in performance optimization. Furthermore, the body mass index showed a positive association, likely reflecting the impact of greater relative muscle mass on power production. These results are in line with previous studies by Gorostiaga et al. (24) and Ferragut et al. (15), which underscore the influence of body composition on athletic performance.

When examining age-based differences, distinct trends were identified across categories. In U-16 players, total arm length was the key determinant of throwing speed, particularly in males, likely due to its role in throw range and angle. In contrast, in the U-18 group, body weight was a significant predictor in males, while in U-21 players, grip strength became the most relevant factor for both sexes. These findings suggest that as players mature physically and gain experience, they are better able to utilize strength-related attributes to enhance performance. This age-related shift in predictive factors is consistent with the findings of Debanne & Laffaye (7) and Tuquet et al. (23) and is further supported by studies showing that elite players achieve higher throwing velocities than recreational athletes, owing to superior physical conditioning and technical development (25-27).

Sex-based differences were also evident, with males consistently exhibiting higher throwing velocities than females. This disparity is likely due to greater muscle mass and advantageous skeletal characteristics in males, as noted in the studies by Tillaar & Ettema (14) and Piscitelli et al. (13).

Importantly, grip strength emerged as a crucial variable in both sexes, reinforcing the need for targeted strength training in this area. Previous research by Ortega-Becerra & Pareja-Blanco (27) has shown that grip strength is directly correlated with throwing speed, particularly in more advanced age categories. Nevertheless, it should be acknowledged that grip strength is not the sole determinant. Other physical qualities—including leg and back strength, as well as trunk rotational power—also play a critical role, as highlighted by Lockie et al. (28) and Razak et al. (29).

In terms of body composition, higher fat-free mass (FFM) and lower fat percentage were positively associated with throwing speed in male athletes. In females, lower fat percentage similarly contributed to improved performance. These outcomes support previous findings from Granados et al. (11) and Hermassi et al. (30), emphasizing the role of muscular development and fat reduction in optimizing athletic performance.

From a practical standpoint, these findings have important implications for training program design. In younger athletes (U-16), technical development and upper-limb strengthening should be prioritized. Particular attention should be given to improving movement mechanics and leveraging anatomical advantages such as total arm length to enhance throwing speed (31, 32). For older age groups (U-18 and U-21), emphasis should shift toward improving body composition and grip strength to support greater force production and technical refinement.

Training programs should also be sex-specific, recognizing the differing physical demands of male and female athletes. In females, strategies should prioritize reducing body fat and increasing grip strength, while in males, efforts should focus on muscle mass development and body composition optimization. These findings also offer valuable insights for talent identification. Key variables such as total arm length, grip strength, and body composition may serve as useful indicators in the scouting and selection process, helping to identify players with physical potential to succeed in competitive handball. This approach could enhance both individual performance and overall team effectiveness.

As for limitations, the main constraint of this study is the sample size—while representative, it could be expanded in future research to improve generalizability. Additionally, incorporating other strength and power assessments, such as the countermovement jump (CMJ) and chest press or maximal deadlift, would offer a more comprehensive understanding of performance. Evaluating somatic maturation could also enrich future analyses by contextualizing the relationship between physical development and performance, as suggested by De La Rubia et al. (33).

This study confirms that throwing speed in handball is influenced by a combination of anthropometric characteristics, body composition, and strength variables. These findings highlight the importance of tailored training programs that consider sex, age, and developmental stage in order to maximize performance and game effectiveness.

Authors' Contributions

All authors equally contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethical Considerations

The study protocol adhered to the principles outlined in the Helsinki Declaration, which provides guidelines for ethical research involving human participants.

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