ANTHROPOMETRIC CHARACTERISTICS, PHYSICAL FITNESS AND THE PREDICTION OF THROWING VELOCITY IN YOUNG MEN HANDBALL PLAYERS

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Abstract:

The objectives of this study were: (i) to analyse anthropometric parameters, physical fitness, and throwing velocity of youth elite male handball players of different ages; and (ii) to develop a multivariate model that explains throwing velocity. Fifty-three male handball players (17.99±1.68 years old), members of the Icelandic national teams, participated in the study. The participants were classified into the U21 (n=12), U19 (n=17), and U17 (n=24) national teams. All were evaluated by basic anthropometry (body height, body mass, body mass index), physical fitness tests (counter movement jump, medicine ball throw, hand dynamometry, 10 m and 30 m sprint, Yo-Yo IR2 test) and ball velocity after various handball throws at goal (a 7-m throw, a 9-m ground shot after a three-step run-up, and a 9-m jump shot after a three-step approach). A one-way analysis of variance with a Bonferroni *post-hoc* test was used to establish the differences between the teams. Multiple linear regression was used to predict speed of the ball from each of the three shots taken for each team. There were no differences between the U21 and U19 teams except for the medicine ball throw, but the U19 team scored better than the U17 team in almost all variables. Ball speed after a handball shot was predicted (between 22% and 70% of accuracy) with only one or two physical fitness variables in each model – medicine ball throw (in four models), counter movement jump (in two models), and 10 m sprint (in two models), being the variables that were most selective.

Key words: *performance, strength, resistance, ball velocity, throwing, power*

Introduction

Team handball (handball) is a physically demanding, high-intensity, body-contact team sport that requires the optimal functioning of both the anaerobic and aerobic energy supplying systems (Nuño, et al., 2016). In particular, handball players have to be able to jump, shoot, block, push, and sprint (Gorostiaga, Granados, Ibanez, & Izquierdo, 2005). Hence, appropriate anthropometric and fitness profiles of players as well as their handball-specific proficiency and other technical factors such as throwing velocity and accuracy are required to perform at a top level (Fieseler, et al., 2017). However, most of the studies that have analysed these aspects were carried out with adult players, with far fewer ones conducted with young players. Knowing how the players' characteristics and/or their skills evolve with age would allow training to be adapted accordingly.

The anthropometric characteristics of elite handball players show that body height and body mass are important for performance in the sport (Gorostiaga, et al., 2005). For youth handball players, however, these characteristics will change dramatically as they grow older, partly because of their natural pubertal development and muscle growth and partly because more emphasis is put on strength training as they get older. These changes are most notable among the U16 and U14 players, or between the players who are before and after their peak-height-velocity age (Hammami, et al., 2018), whereas a study comparing elite male U18 and U16 players (Ingebrigtsen, Jerrreys, & Rodahl, 2013) found no differences in their anthropometric characteristics, i.e. body height, body mass, body mass index (BMI), and reciprocal ponderal index (RPI). The results of another study of adolescent handball players were similar, with no differences being found in body height, body mass, or body fat between age groups (Matthys, Frasen, Vaeyens, Lenoir, & Philippaerts, 2013b). Longitudinal studies, however, do show differences in anthropometric characteristics (Matthys, et al., 2103a; Visnapuu & Jurimae, 2009). With respect to physical fitness, the few studies that have analysed age differences in the various parameters found at most only slight differences. Thus, two studies found no difference in countermovement jump (CMJ) between the U18 and U16 players (Ingebrigtsen, et al., 2013; Ortega-Becerra, Pareja-Blanco, Jimenez-Reyes, Cuadrado-Panafiel, & Gonzalez-Badillo, 2018). Nevertheless, studies comparing younger groups did find differences: U13 vs U11 (Visnapuu & Jurimae, 2009), U15 and U17 vs U11 and U13 (Ingebrigtsen, et al., 2013), and U16 vs U14 (Hammami, et al., 2018). In regard to sprint tests, two studies reported no difference in sprint times between the U16 and U18 teams (Ingebrigtsen, et al., 2013; Ortega-Becerra, et al., 2018), but several other studies of younger age groups did find differences (10 m, 20 m, and 30 m sprints) (Hammami, et al., 2018; Matthys, et al., 2013a; Matthys, Vaeyens, Coelho-e-Silva, Lenoir, & Philippaerts, 2012; Ortega-Becerra, et al., 2018). Only one study (Matthys, et al., 2013a) has examined the relationship between endurance and age groups. In it, over a period of three years, the young male handball players increased their running distance in the Yo-Yo IR1 running test (Matthys et al., 2013a).

Handball throwing is one of the most important technical skills. Shooting is considered a kind of throwing, the objective of which is to score a goal, therefore it should be executed powerfully and accurately. About seven shots on goal per player are taken in a handball game in Portuguese National League (Povoas, et al., 2012). The commonest are jump shots (75%) and ground shots (15%) (Wagner, Finkenzeller, Wurth, & von Duvillard, 2014).

There have been few studies analysing the evolution of throwing velocity with age. In the Spanish league, the differences have been found between the U16 and U18 players in both the ground and jump shots (Ortega-Becerra, et al., 2018). There is interest in knowing which players' abilities and skills influence throwing velocity since, together with accuracy, it is one of the most relevant factors determining scoring. Thus, in a study with the Tunisian league players, the variable that presented the closest relationship (by means of a simple linear regression) with throwing velocity from the 7-metre standing throw, from the overarm shot after a three--step run-up, and from the jump shot was 1-RM clean and jerk (R^2=.56, R^2=.39, R^2=.43, respectively) (Hammami, et al., 2018). On the contrary, studies with the German first division players found a correlation between body mass and throwing velocity of the a jump shot (Schwesig, et al., 2017) and between body height and ball velocity of the ground shot (Fieseler, et al., 2017). A more recent study (McGhie, Osteras, Ettema, Paulsen, & Sandbakk, 2018) focused on the association of the height of the jump before a shot and speed of the thrown handball; it was found that the maximum strength at a low load was significantly correlated with height in the jump shot movement, and that associations with measures of strength (1RM, unilateral leg press) were weaker for height in the jump shot movement than the CMJ height. In young players, throwing speed (of both the ground and jump shot) has shown correlations with multiple variables (10 m and 20 m sprints, CMJ, and squat jump) (Ortega-Becerra, et al., 2018).

From the above, it is clear that the findings of the few studies on the relationship between the chronological age of youth elite men handball players and their anthropometric, physical fitness with throwing velocity tend to be inconsistent. Also, it must be mentioned that no study so far has analysed, from a multivariate perspective, which anthropometric or physical fitness parameters may be used to predict throwing velocity. Therefore, the objectives of the present study were: (i) to analyse anthropometric parameters, physical fitness, and throwing velocity in youth men handball players of different age categories; and (ii) to develop a multivariate model that explains throwing velocity.

Methods

Subjects

Fifty-three male handball players (age 17.99±1.68 years), members of the Icelandic national teams, participated in the study. The participants were classified into the Under-21 (U21) national team (n=12), Under-19 (U19) national team (n=17) and Under-17 (U17) national team (n=24). U21 took part in the World Championship in Algeria (July 2017) and achieved the 12th place. U19 participated in the World Championship in Georgia (August 2017) and achieved the 10th place. The U17 team took part in the Youth Olympic Games in Hungary (July 2017) and achieved the 8th place. In 2018, the U21 team is ranked 10th and U19 is ranked 16th by IHF. There was no ranking for the U17 team. Overall, the men's teams are ranked 12th (http://www.ihf.info/). The study was approved by the Ethics Committee of Reykjavik University, and respected the principles of the Declaration of Helsinki. It was carried out during the national teams' training camp.

Procedures

A cross-sectional study was designed. In the first part of the study, the independent variable was the age group (U21, U19, and U17), whereas the dependent variables were anthropometric and fitness parameters and throwing velocity. All the tests were used in previous studies (Lidor, et al., 2005; Matthys, et al., 2012, 2013a, 2013b; Saavedra et al., 2018). In the second part of the study, a multivariate model (multiple linear regression) was developed for each age group, determining the predictive variables of throwing velocity for each shot: 7-m throw (standing), 9-m ground shot after a three-step run-up, and 9-m jump shot after a three-step approach.

All subjects took a comprehensive battery of tests, which included anthropometry, physical fitness tests, and throwing velocity. The anthropometric measurements were taken in accordance with the International Society for the Advancement of Kinanthropometry's standardized procedures (ISAK, 2011): body height, body mass, BMI (Keys & Brozek, 1953), and reciprocal ponderal index (RPI; Nevill, Holder, & Watts, 2009). The RPI power was calculated as RPI=body height (cm)/ body mass (kg)$^{0.333}$, using a Seca model 769 scale. The physical fitness tests used were: CMJ, medicine ball throw, hand dynamometry, 10 m and 30 m sprint, and yo-yo intermittent recovery level 2 test (Yo-Yo IR2). All these tests have been used in previous handball studies. CMJ with the hands on the hips (Bosco, Luhtanen, & Komi, 1983) was evaluated by measurements of high-speed video recordings (Casio, EXILIM EX-F1, 300fps and 512×384 pixels) using the open-licence software package Kinovea (Kinovea 0.8.15 for Windows; available at http://www.kinovea.org). The camera was placed on a tripod at a distance of 1.5 m perpendicular to the players' sagittal plane and the filming zone. The jumping zone was marked out on the floor. Once the jumps made by the players had been filmed, the jump time was calculated using the Kinovea software, and the jump height was estimated (Balsalobre-Fernandez, Tejero-Gonzalez, del Campo-Vecino, & Bavaresco, 2014). Jump height (cm) and peak power (W) were evaluated, with the latter calculated as CMJ(W)=[60.7×body height (cm)]+[45.3×body mass (kg)]-2055 (Sayers, Harackiewicz, Harman, Frykman, & Rosenstein, 1999). Medicine ball (3 kg) throw with one knee on the floor (as adapted by Lidor, et al., 2005) was scored as a distance (m) achieved. Hand dynamometry of the dominant hand (Council of Europe, 1988) was evaluated with a Vernier hand dynamometer (Vernier, Orlando, USA), with the subject seated and the elbow at 90°. The 10 m and 30 m sprints (as adapted by Lidor, et al., 2005) were evaluated with photocells (TCi Wireless Timing System, Brower Timing Systems, Draper, Utah, USA). The yo-yo intermittent recovery level 2 test (Bangsbo, Iaia, & Krustrup, 2008; Krustrup, et al., 2006) was scored as the maximum speed (km/h) achieved. All the tests except the hand dynamometry and Yo-Yo test were done twice, and only the better of the two scores was recorded. A maximum throwing velocity was evaluated with a radar gun (Perform Better, Warwick, UK) located behind the goal, measuring three types of shot made with no opposition or any instructions regarding accuracy: 7-m standing throw (Gorostiaga, et al., 2005), 9-m ground shot (known also as overarm shot or supported shot) after a three-step run-up (Gorostiaga, et al., 2005), and 9-m jump shot after a three-step approach (Vila, et al., 2012). The latter two shots were executed from the playing position of the centre back. Each shot on goal was done twice with maximum effort, and only the better score in each case was recorded. The order of shot executions was: 7-m throw, ground shot, jump shot. After the anthropometry measurements, the subjects performed a standardized warm-up procedure consisting of a stretching exercise, 4-6 repetitions of 30 m running with different exercises (knees up, lunge walk, etc.), 5-7 accelerations over 30 m building up running speed, and 10 minutes of passing in pairs over various distances. Full recovery was ensured between each of the trials.

Statistical analyses

All the variables satisfied the tests of homoskedasticity (Levene's homogeneity test) and normality (Kolmogorov-Smirnov test). The basic descriptive statistics (mean and standard deviation) were calculated. A one-way ANOVA was used to examine differences between the teams (U21, U19, and U17). The Bonferroni *post-hoc* test was used to compare means. The eta-squared (η^2), which is an effect size measurement for the analysis of variance, was calculated to know the magnitude of differences. Multiple linear regression (MLR) models were developed using the stepwise selection procedure. Throwing velocity (7-m standing throw, 9-m ground shot from a run-up, and 9-m jump shot) was the predicted variable (dependent variable) and anthropometric and physical fitness characteristics were the independent variables. Three MLR models, one for each shot, were computed for each age group (U21, U19, and U17). The stepwise selection procedure consists in removing the variable with the largest probability of *F* if a certain pre-established value is exceeded (i.e. $p \leq .10$). The equation is recomputed without the variable and the process is repeated until no more independent variables can be removed. Then, the independent variable not in the equation with the smallest probability of *F* is entered if the value is smaller than a certain pre-established value (i.e. $p \leq .05$). All variables in the equation are again examined for removal. This process continues until no variables in the equation can be removed and no variables in the equation are eligible for entry, or until the maximum number of steps has been reached. Both the linearity and the homoskedasticity assumptions were acceptable according to a scatterplot of the residuals. The ranges of the variance inflation factor for all the independent variables were between 1.00 and 1.24, and they showed no collinearity. The Durbin-Watson statistic was calculated and showed that there was no autocorrelation in the residuals (the values of the statistic ranged from 1.06 to 2.25). The level of significance for all statistical tests was set at p≤.05. All calculations were performed using SPSS version 20.0.

Results

Table 1 lists means and standard deviations of each variable, and the results of the one-way ANOVA. There were no differences between the U21 and U19 players except in the medicine ball throw. The lowest scores were attained by the U17 players in all the variables except in body height, RPI, and the Yo-Yo IR2 test.

Table 2 presents the results of the multiple linear regression of each shot by the teams. In the 7-m standing throw, the model predicted between 24.4% (U19) and 43.1% (U21) of the variance in throwing velocity with several variables. In the 9-m ground shot from a three-step run-up, the model predicted between 22.2% (U19) and 53.1% (U17) of the variance of throwing velocity with the medicine ball throw (except for U21, for which the predictor variable was the 10 m sprint). Finally, in the 9-m jump shot, the model predicted between 30.3% (U19) and 70.4% (U21) of the variance of throwing velocity with CMJ or the medicine ball throw.

Table 1. Mean and standard deviation of each variable. Means were compared between teams by a one-way analysis of variance (ANOVA) with Bonferroni post-hoc test and eta-squared

Variable	U21 n=12	U19 n=17	U17 n=24	F	p	η²	Differences
	M ± SD	M ± SD	M ± SD				
Anthropometry							
Body height (m)	1.88±0.06	1.87±0.05	1.84±0.05	1.917	.158	0.071	n.s.
Body weight (kg)	86.16±7.55	84.51±10.50	76.4±8.40	6.482	.003	0.206	U21, U19 > U17
BMI (kg/m²)	24.45±1.68	24.20±2.49	22.48±2.05	4.847	.012	0.162	U21, U19 > U17
RPI (cm/kg)	42.60±1.06	42.72±1.46	43.57±1.38	2.960	.061	0.106	n.s.
Physical fitness							
CMJ (cm)	51.77±5.01	49.18±5.08	44.94±4.49	8.388	.001	0.259	U21, U19 > U17
CMJ (W)	5506±497	4758±470	4133±374	18.531	<.001	0.436	U21, U19 > U17
Medicine ball throw (m)	8.75±1.23	7.69±0.91	7.07±0.65	12.531	<.001	0.348	U21 > U19 > U17
Hand dynamometry (N)	401.28±61.52	386.41±62.21	354.79±49.09	3.188	.050	0.113	U21 > U17
10m sprint (s)	1.71±0.06	1.74±0.07	1.80±0.61	6.525	.003	0.221	U21, U19 < U17
30m sprint (s)	4.14±0.21	4.24±0.17	4.37±0.17	6.380	.004	0.217	U21, U19 < U17
Yo-yo IR2 test (km/h)	20.31±0.70	19.70±0.80	19.77±0.68	2.236	.119	0.092	n.s.
Ball speed after a handball shot							
7m throw (km/h)	88.10±7.77	85.94±7.23	76.92±6.73	12.444	<.001	0.341	U21 > U17
9m g. shot after run-up (km/h)	89.21±7.76	87.71±6.10	79.04±6.73	10.626	<.001	0.311	U21,nU19 > U17
9m jump shot (km/h)	84.20±8.07	82.59±4.23	75.04±6.90	167.109	<.001	0.304	U21 > U17

Note. g - ground; n.s. – not significant.

Table 2. Multiple linear regression for each throw and team

Shot	Team	R	R²	ΔR²	SEE	B	SE	β	t	p	Selected variable
7m throw	U21	0.698	0.488	0.431	4.212	-47.887	16.365	-0.698	-2.962	.017	10m sprint
	U19	0.546	0.298	0.244	6.703	-24.155	10.290	-0.546	-2.347	.035	30m sprint
	U17	0.680	0.463	0.409	5.121	-1.256	0.580	-0.397	-2.165	.043	Medicine ball throw, BMI
9m ground shot after run-up	U21	0.685	0.469	0.410	4.241	-46.439	16.475	-6.085	-2.189	.020	10m sprint
	U19	0.527	0.277	0.222	5.703	3.915	1.753	0.527	2.233	.044	Medicine ball throw
	U17	0.744	0.544	0.531	4.554	7.668	1.540	0.744	4.980	.001	Medicine ball throw
9m jump shot	U21	0.861	0.741	0.704	4.158	0.013	0.003	0.861	4.478	.003	CMJ
	U19	0.594	0.352	0.303	3.759	0.006	0.002	0.594	2.260	.020	CMJ
	U17	0.583	0.340	0.308	5.727	6.189	1.882	0.583	3.288	.004	Medicine ball throw

Discussion and conclusions

Just a few studies so far have analysed the differences between players of different age categories in anthropometric and physical fitness parameters. These studies were carried out with professional league players (Ortega-Becerra, et al., 2018), with small samples (n=29) (Ingebrigtsen, et al., 2013), with women players (Saavedra, et al., 2018), or with younger players than those of the present study (Hammami, et al., 2018; Matthys, et al., 2013a, Visnapuu & Jurimae, 2009). Likewise, other studies have analysed the relationship of different parameters with throwing velocity (Fieseler, et al., 2017; Hammami, et al., 2018; Ortega-Becerra, et al., 2018; Schwesig, et al., 2017) but, to the best of our knowledge, our study has been the first to develop a multivariate model predicting throwing velocity. In general, no differences were found between the U21 and U19 teams, although the U19 team did obtain better results than the U17 team in almost all the variables (Table 1). On the other hand, throwing velocity was predicted (between 22% and 70%) with only one or two physical fitness variables in each model, with medicine ball throw (four models), CMJ (two models), and 10 m sprint (two models) being the variables most commonly selected by the different models (Table 2).

Regarding the differences between the teams in anthropometry, physical fitness, and throwing velocity, only one variable (medicine ball throw) showed differences between all the three age groups. With regard to the anthropometric parameters, there were no differences between the three teams in body height or RPI, but U21 players were heavier and had a greater BMI than U17. Body weight is very important in a full body contact sport like handball, and one study has shown players at a higher level of performance to be heavier than those at a lower level (Gorostiaga, et al., 2005). Similarly, higher level players have greater muscle mass than those of a lower level (Gorostiaga, et al., 2005). The absence of body height differences between the three teams may be due to the particular characteristics of the players. Nonetheless, there appears to be a difference (although bellow statistical significance) of four centimetres between the U21 and U17 teams. The values presented are similar to those of other elite players in Norway (U16: 183±5.3 cm; U18: 185±4.9 cm) (Ingebrigtsen, et al., 2013) and Spain (U18: 1.83±0.06 cm; U16: 1.72±0.09 cm) (Ortega-Becerra, et al., 2018). To all this, one must add that there could be anthropometric differences that depend on the player's position (Schwesig, et al., 2017), but the present study did not differentiate the subjects in accordance with this criterion. With respect to physical fitness, the U21 team did not perform better than U19 in any of individual tests included in the battery except, as was noted above, for the medicine ball throw. Furthermore, U17 had the lowest score in six out of the ten physical fitness variables tested, namely CMJ (W/cm), medicine ball throw, 10 m and 30 m sprints, and maximal throwing velocity of the 9-m ground shot after run-up. These results are in opposition to previous studies which found no differences in CMJ (Ingebrigtsen, et al., 2013; Ortega-Becerra, et al., 2018), although such differences did exist in younger age groups (Hammami, et al., 2018; Ingebrigtsen, et al., 2013; Visnapuu & Jurimae, 2009). The case is somewhat similar with the 10 m and 30 m sprints for which we found differences between U19 and U17, while previous studies with similar age groups found no such differences (Ingebrigtsen, et al., 2013; Ortega-Becerra, et al., 2018). Again, however, these differences did exist in younger age groups (10 m, 20 m, and 30 m sprints) (Hammami, et al., 2018; Matthys, et al., 2012, 2013a; Visnapuu & Jurimae, 2009). There were no differences between any of the three age groups in the Yo-Yo IR2 test, indicative of a good aerobic fitness of the youngest team (U17). These results are, however, contrary to those of a study of young male handball players whose running distance increased in the Yo-Yo IR1 test over a period of three years (Matthys, et al., 2013a). In general, the results seem to indicate that maturation has no further influence on anthropometric and physical fitness parameters after 19 years of age (Hammami, et al., 2018). Finally, throwing velocity was recorded in three different types of shooting – from a 7-m standing throw, 9-m ground shot after a three-step run-up, and 9-m jump shot . The only differences found were a greater velocity attained by the U21 players than U17 for all the types of shooting. This might indicate that players have not reached their full throwing velocity potential (standing throwing, ground shooting and jump shooting alike) until U21. On average, the fastest shots were after a three-step run-up ground shots for U17 and U19, but not for U21 (tied with the 7-m throw). The average score in ground shots after a run-up of all the three national teams was considerably lower than reported for top level Spanish professional players (Rivilla-Garcia, Grande-Rodríguez, Chirosa, Gómez-Ortiz, & Sampedro Molinuevo, 2011), but higher than in Tunisian players (Chelly, Hermassi & Shephard, 2018).

With respect to the multiple linear regression model used to predict the speed of each of the three shots (7-m standing throw, 9-m ground shot after a three-step run-up, and 9-m jump shot) in each of the three teams (U21, U19, U17), the medicine ball throw proved the best predictive variable with all the types of shot in U17. Indeed, a strong bivariate correlation has already been reported between how well this physical exercise is performed and handball shots (Ortega-Becerra, et al., 2018). The suggestion arises therefore that this simple and general test could be applied to the general juvenile population in search of those subjects with the greatest predisposition to attaining a high throwing velocity. Interestingly, CMJ was the variable that predicted 70% and 30% of the variance in a handball jump shot for U21 and U19, respectively. This is especially relevant given that 75% of the shots in a match are taken from a jump after a run-up (Wagner, et al., 2014). Surprisingly, body height was only indirectly included (via the BMI) in the model for the 7-m throw to best predict maximal throwing velocity (41%). Earlier studies have reported a relationship between body longitudinal measures and throwing velocity, with a greater height, arm-span, and hand length being advantageous for shooting faster (Zapartidis, Kororos, Christodoulidis, Skoufas, & Bayios, 2011), and simple correlation have been found between body mass and jump shot throwing velocity (Schwesig, et al., 2017) and between body height and the ground shots throwing velocity (Fieseler, et al., 2017). Finally, the variable most frequently selected by the models (four times) was the medicine ball throw, which can be taken to be a functional assessment of strength. In this sense, in a recent study with players of the Tunisian league (which, however, used simple linear regression and not multiple as in the present work) found throwing velocity of a 7-m throw, ground shot after a run-up, and jump shot to be related to 1-RM clean and jerk (R^2=0.56, R^2=0.39 and R^2=0.43, respectively) (Hammami, et al., 2018).

The present study has several limitations. First is a cross-sectional nature of the data limiting our ability to better understand physical development taking place during these years of late adolescence and early adulthood. Second is the absence of data regarding the physical (biological) maturity or body composition of the players. While these two evaluations would be highly relevant, they are very time consuming. The data collection was done during the training camps, so the coaches and the team of researchers decided to dispense with these evaluations in order to optimise the use of the time available. Third, while all the three types of handball shot studied are very sport-specific movements, the factors used to predict their throwing velocity represent very general physical parameters, again highlighting the importance of also testing movements that are specific to each sport (McGhie, et al., 2018). This can be done through specific handball tests, such as those of game-based performance (Wagner, et al., 2018; Wagner, Sperl, Bell, & von Duvillard, 2019). Fourth, the position of the players was not taken into account, and this could influence the variables studied (Karcher & Buchheit, 2017; Schwesig, et al., 2017).

In summary, the present study did not find any differences between the U21 and U19 teams in any of the variables studied except for the medicine ball throw. There were, however, various differences between the U19 and U17 teams: body weight, BMI, CMJ (cm and W), medicine ball throw, 10 m and 30 m sprints, and distant ground shot throwing velocity. The medicine ball throw did predict throwing velocity in the three types of shots studied for the U17 team. For the U21 team, the predictor variables were 10 m sprint (7-m standing throw and 9-m ground shot after a three-step run-up) and CMJ (9-m jump shot). Finally, for the U19 team, different variables were predictors of throwing velocity in each of the three types of shot. In this way, the present study provides valuable information for coaches, giving a deeper insight into the physical attributes behind throwing velocity of youth elite male players. The results can provide a benchmark for physical attributes of the youth national teams in the respective country, and at the World Championship level. Researchers and coaches can also refer to this study when deciding on which tests to include in a battery of tests for youth elite men players at a regional or national level. The main findings suggest that there is little to no physical performance difference between U19 and U21. This seems to suggest that it is necessary to systematically add training hours to stimulate further physical gains. Adding to the existing literature, we found that, although shooting is a highly specific whole-body movement, throwing velocity in handball can be partially explained by such general physical tests as medicine ball throw, sprints, and CMJ. Coaches could find a practical application of these findings and they may assist them in their program design. In general, it is possible to indicate that handball coaches cannot overlook the importance of a lower limb (explosive) power to improve maximal throwing velocity. Lower body physical development should be regarded of equal significance as that of the upper body in training handball players. Players should perform general strength and power training as this can promote physical adaptations that aid handball performance (Dello Iacono, Karcher, & Michalsik, 2018). The emphasis should be on increasing muscle mass for U17, and on power development for U19 and U21 players.

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