Predicting the throwing velocity of the ball in handball with anthropometric variables and isotonic tests

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Predicting ball-throwing velocity in handball

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Abstract

The goal of this study was to 1) investigate general body influence, hand-specific anthropometric parameters, and upper-limb power and strength on ball-throwing velocity in a standing position (V_{ball}); and 2) predict this velocity using the multi-regression analysis method. Forty-two skilled male handball players (age = 21 y±2.99; body height = 1.81 m±0.07; body mass =78.3 kg±11.3) participated in this study. We measured general anthropometric parameters (body height, body mass, lean mass, BMI) and handball-specific anthropometric parameters (hand size and arm span). Upper-limb dynamic strength was assessed using a medicine ball (2 kg MB) throwing test, and power through a maximal one-repetition bench-press test (1-RMBP). All the variables studied were correlated with Ball velocity. The 2 kg MB throwing performance was the best predictor (r=0.80). General anthropometric parameters were better predictors (r=0.55-0.70) than hand-specific ones (r=0.35-0.51). The best multiple regression model accounted for 74% of the total variance and included body mass, 2 kg MB performance and power output at the 20 kg-bench-press. The equation found could help trainers, athletes and professionals detect future talents or test athletes' current fitness levels.

Introduction

For many authors, ball throwing velocity (V_{ball}) is a successful factor in handball (e.g. Hoff, J, Almasbakk, 1995; Gorostiaga, Izquierdo, Iturralde, Ruesta, & Ibanez, 1999; Gorostiaga, Granados, Ibanez, Gonzalez-Badillo, and Izquierdo, 2006). This velocity depends primarily on the player's ability to accelerate the ball with an over-arm throw. Shoulder internal rotation and elbow extension are two important factors (e.g. Fradet *et al.*, 2004; Van den Tillaar & Ettema, 2004a; 2007). Other performance factors depend on the duration of the movement, which reduces visual information for the goalkeeper, and the accuracy of the throw (Bayios & Boudolos 1998). One of the main concerns for both coaches and athletes is the possibility of predicting the ball velocity. We investigated three major ways for this purpose.

First, body height affects the outcome of physical tests (McMahon, 1984; Astrand and Rothal, 1986; Jaric, 2003). So, it seems that anthropometric variables should be taken into account for prediction. Indeed, several studies showed significant and positive correlations between the ball velocity and general anthropometric variables [r= .23 - .62]: body mass, lean body mass, body height and BMI (e.g. Skoufas, Katzamanidis, Hatzikotoylas, Bebetsos & Patikas 2004; Van den Tillaar & Ettema 2004b; Vila *et al.*, 2009; Zapartidis *et al.*, 2009). Other studies considered specific handball anthropometric parameters (hand size and arm span) and highlighted significant and positive correlations [r= .29 - .37] with ball velocity (Skoufas *et al.*, 2004; Zapartidis, *et al.*, 2009). However, although general and specific anthropometric parameters seem to be related to the ball velocity, they have a low predictability level. Moreover, in all these studies, general anthropometric parameters are better predictors than specific ones.

Secondly, studies have shown that ball velocity is related to physical fitness characteristics, especially power and strength. Muscle power is considered an important parameter responsible for successful rapid movements performed with maximum effort, such as throwing (Newton & Kraemer, 1994). To measure upper-limb strength and power, isotonic tests seem to be the most appropriate to handball specificity (Fleck *et al.*, 1992; Marques *et al.*, 2007). Studies used the bench-press test for power and strength assessment with male players in order to predict ball velocity. They showed positive and significant correlations with the one maximum strength bench-press (r=.63 for Marques *et al.*, 2007) and with bar velocity [r= .67- .71] with lower loads (Gorostiaga, Granados, Ibanez and Izquierdo, 2005; Marques *et al.*, 2007). This shows that upper-limb strength and power tests are linked with ball velocity, and with a higher correlation than those with anthropometric variables. In order to find a more accurate strength test, closer to over-arm throwing kinematics, Pineau, Horvath & Landuré (1989, 1992) used a 2 kg medicine ball throw as an isotonic test to assess upper-limb power and strength. The results showed that this test was best in assessing the level of each handball player.

Lastly, few studies have investigated combining predictive models with anthropometric and motor ability parameters. To our knowledge, only Eliasz and Wit (1996) have investigated the influence of basic anthropometric and motor ability parameters on ball velocity in handball. These authors confirmed that physical fitness had a greater influence than anthropometric parameters, especially when considering trunk flexor muscle strength and maximal arm speed. This statistical design predicted the ball velocity more accurately by combining the best predictors.

So, this short review shows that general, hand-specific anthropometric parameters and upper-limb strength tests are linked to throwing velocity. However, none of these studies is able to predict throwing velocity accurately, using a simple correlation. So, the goal of this study is to 1) investigate the influence of the general body, specific anthropometric parameters, as well as the upper-limbs on standing ball-throwing velocity; and 2) predict this velocity by combining the best predictive parameters.

Method

Experimental approach to the problem

A multiple-regression statistical design was used to determine the effect of anthropometric and physical parameters on the ball velocity. Sixteen independent variables were divided into two groups: 1) anthropometric parameters, (a) four general parameters: body mass, lean mass, body height, body mass index, and (b) five specific anthropometric parameters: arm span, finger span, hand perimeter, ring-finger length and middle-finger length; and 2) seven physical fitness parameters: medicine-ball throwing (2 kg), and six variables recorded or calculated during the bench-press test: the one-repetition maximum bench-press (1-RMBP), force, velocity and power output at 20 kg, maximum power and bar velocity at 30% of 1-RMBP. The dependent variable was the ball velocity in standing position.

Participants

Forty-two skilled male handball players (Table 1) participated in this study. The sample was composed of players playing at three different levels in the French championship (local, high regional and high national levels, corresponding respectively to the third, sixth and ninth divisions). All players had at least two years of experience in competition with at least two training sessions per week. They were all in good physical condition, with no injuries or disabilities. Each volunteer signed a written statement of informed consent after receiving an oral and written description of the procedures approved by our university's ethics committee, and was informed of the risks and benefits of participation in the study.

***** Insert Table 1 about here*****

Procedures

First, we measured participants to record their body height, arm span, and hand-specific parameters. We weighed them on bioelectric impedance scales. Then, after a five-minute warm-up, participants performed a series of medicine-ball throws. After a 30-minute rest, they performed a series of five ball throws recorded using a radar gun. The best three performances (maximum velocity) were saved for further analysis to calculate mean velocity. The next day, during a second session, we measured power, strength and bar velocity for each athlete during a bench-press test.

Anthropometric parameter measurement

We followed the standardized techniques recommended by the International Society for the Advancement of Kinanthropometric (Marfell-Jones, Olds, Stewart & Carter, 2006). Body height and arm span were measured using an anthropometer, with 0.1 cm accuracy. Body mass was measured using bio-electric impedance scales (Weinberger model DJ-156; Weinberger GmbH & Co, Germany), with 0.1% accuracy. The methods of Visnapuu and Jürimäe (2007) were used to measure hand-specific anthropometric parameters: finger length from the tip of the thumb to the tip of the ring finger, finger length from the tip of the thumb to the tip of the middle finger, finger span, and hand perimeter. Measurement accuracy was 0.1 cm. Hand anthropometry was repeated twice with a one-hour interval to calculate measurement reliability. Intra-class correlation (ICC) was 98%.

Upper-limb strength and power measurement

Available data suggested several specific methods to estimate muscle power (Van Praagh & Dore, 2002). We chose two isotonic tests: (1) upper-limb explosive power was assessed using a medicine-ball-throwing test (Pineau *et al.*, 1989; 1992; Katic, Cavala & Srhoj, 2007). In this test, participants were instructed to throw a medicine ball as far as they could (mass: 2 kg, perimeter: 56 cm), in a kneeling position, holding the ball over their heads. This position was chosen to evaluate upper-limb strength alone (Pineau *et al.*, 1989; 1992) and not lower-limb strength. Each subject performed five trials with a one-minute rest between trials. The best two performances were saved and averaged for further analysis. ICCs were 95%. A soft mat was rolled out on the floor, on which the medicine ball mark could easily be located and measured with a 20-meter tape measure with about 2 cm accuracy. (2) Upper-limb power and strength were assessed via a one-repetition maximum bench-press using a free weight barbell machine. In this test, the participants were instructed to take hold of the bar (step 1), position it on their chest (step 2), then raise it as quickly as they could until their elbows were fully extended (step 3). All participants used an initial mass of 20 kg. Increments were calculated using an isoinertial dynamometer (Myotest S.A., Switzerland). The myotest device was placed on the bar and monitored the three bench-press test steps with beep signals. After each trial, this recognized device (Jidovtseff, Crielaard, Croisier & Cauchy, 2008) calculated the velocity at which the bar had been pushed. The software then gave the next increment. When velocity was too slow (less than 100 cm/s), the test was stopped. Then, the software calculated the velocity, maximum power, strength and one-repetition maximum for each bar. We recorded the velocity for the first bar lifted and the power and strength output for the first three bars for further analysis. The one-repetition maximum was assessed using a single regression equation based on the velocity recorded for each bar (Figure 1). The software directly calculated a reliability index. All indices higher than 90% were saved for further analysis. If the indices were lower than 90%, the participants performed the test again the next day. All participants were successful with these criteria.

***** Insert Figure 1 about here*****

Throwing velocity measurement

The ball velocity was evaluated by an over-arm throw in a standing (i.e. stationary) position, with both feet on the ground as for penalty throws. After a 10-minute warm-up, the subject was instructed to throw a standard handball (mass: 0.480 kg; circumference: 0.58 m) at maximal velocity at a 0.5 x 0.5 m target located in the middle of a standard handball goal (2 x 3 m) located seven meters away . No advice was given regarding throwing technique. Each subject performed five trials with a one-minute rest between trials. The best three performances were saved and averaged for further analysis. The coach supervised each throw to ensure that they complied with handball rules, with both feet firmly planted on the ground. The ball velocity was recorded using a Doppler-radar gun (MATSPORT TRAINING, Radar ATS) with a frequency of 250 Hz and ±0.027 $m.s^{-1}$ accuracy. The radar gun was located three meters behind the player, in the thrower-target axis at a height corresponding to the player's height. In order to be as accurate as possible, only throws hitting the target were recorded for further analysis. The ICC was 95%.

Statistical Analysis

The analyses were done using STATISTICA software (Version 7, Statsoft, Inc). First, Pearson correlation coefficients were used to determine the relationship between independent variables. Then, a multiple-regression analysis technique was applied to identify the most predictive models. The basic model used the general linear model

$$Y = \beta_1 x_1 + \beta_2 x_2 \, \beta_3 x_3 + \beta_4$$

where Y, the dependent variable, representing ball velocity, is normally distributed, x_i is the i^{th} predictor and β_i the coefficient. Descriptive statistics were used to verify that the basic dependent variable normality assumption was met. Distribution normality tests and skewness revealed no abnormal data pattern. For each variable, the 95% limits of agreement (LOA) and coefficients of variation (CV) were calculated (Atkinson & Nevill, 1998). Additionally, in order to validate the applicability of the multiple-regression equation, using the same protocol, we tested a twelve-player independent sample (skilled handball players studying in our university's sport science department) by using the Howell method (2010) . We used a paired T-test for each variable within the equation (comparison between the observed and the theoretical value of the coefficients in the equation). A 0.05 α level was used for all statistical tests.

Results

The ball velocity mean value in the standing position was 21.70±2.53 $m.s^{-1}$ and ranged from 15.78 $m.s^{-1}$ to 26.50 $m.s^{-1}$.

*****Insert Table 2 and 3 and Figure 2 about here*****

Anthropometric parameters

All the mean, minimum and maximum values and correlations are summarized in Tables 2 and 3. All the general anthropometric parameters (body mass, lean mass, body height, BMI) were correlated with the throwing velocity (r>0.55; p<.001). The *r* values ranged from .55 (body height) to .70 (body mass). The specific anthropometric parameters were also correlated with the ball velocity but with lower links (Table 3). The *r* ranged from .35 (finger span) to .51 (arm span).

Isotonic tests

All these results are summarized in Table 4. The 1-RMBP mean value assessed during the bench-press test was 73.3±14.0 kg. It ranged from 49 kg to 106 kg and significantly correlated with ball velocity (r=.55; p<.001). The force output during the first bar was 410±49.5 N. It ranged from 294 to 538 N and significantly correlated with ball velocity (r=.63; p<.001). The maximum power mean value was 675.1±188 W and was obtained at an average load corresponding to 42.5% of the 1-RMBP. Values ranged from 340 to 1138 W and significantly correlated with ball velocity (r=.65; p<.001). The power output at the first bar was 625.7±160.8 W; it ranged from 320 to 1046 W and significantly correlated with ball velocity (r=.65; p<.001). The velocity of the bar at 20 kg was 2.09±0.32 $m.s^{-1}$, it ranged from 1.38 to 2.80 $m.s^{-1}$ and significantly correlated with ball velocity (r=.59; p<.001). The bar velocity at a load representing 30% of 1-RMBP was 2.025±0.21 $m.s^{-1}$, it ranged from 1.45 to 2.37 $m.s^{-1}$, and significantly correlated with ball velocity (r=.45; p=.003).

****Insert Table 4 and Figures 3 & 4 about here****

The 2 kg MB throwing mean performance was 9.72±1.8 m and ranged from 6.84 m to 13.22 m. This isotonic test was highly correlated with ball velocity (r=.80; p<.001).

Multiple regression model

****Insert Table 5 about here****

Furthermore, we tested all the models that include the parameters significantly correlated with ball velocity. The best ones are summarized in Table 5 and classified in four categories: anthropometric models (general and handball specific), physical fitness models and combined models.

First, the general anthropometric model accounted for 52.8% of the total variance and included all general anthropometric variables (body mass, body height, BMI and fat-free mass). Secondly, the best specific anthropometric model accounted for 36.0% of the total variance and included hand perimeter, finger span, ring finger length, middle finger length and arm span. Thirdly, the best physical fitness models accounted for 67% of the total variance. This model included medicine-ball throwing performance, power and force output in the 20 kg-bar bench-press. Lastly, by combining anthropometric and physical fitness parameters, two models were retained with correlation coefficients of .85 and .86 ($p<0.00001$), accounting for respectively 72 and 74% of the total variance. The error terms were respectively 1.33 $m.s^{-1}$ and 1.35 $m.s^{-1}$. These models included body mass, medicine-ball performance and either force output at 20 kg bench-press or 1-RMBP.

Discussion

In this study, we examined the effect of general and specific anthropometric parameters on standing throwing performance and isotonic tests. The standing throwing velocity observed in the present study was 21.70±2.53 $m.s^{-1}$. These results are in keeping with the data hitherto available with adult male samples. Indeed, with elite handball players, standing throwing velocity was 23.8±1.9 $m.s^{-1}$ (Gorostiaga *et al.* 2005), 24.45±1.97 $m.s^{-1}$ (Wit & Elias, 1998) and 23.51±2.23 $m.s^{-1}$ (Bayos & Boudolos, 1998). With experienced handball players, playing in second and/or third division, standing throwing velocity was 23.2±1.6 $m.s^{-1}$ (Van den Tillaar and Ettema, 2004b) and 21.8±1.6 $m.s^{-1}$ (Gorostiaga *et al.* 2005). With novice handball players or physical-education students, standing throwing velocity was 17.99±0.22 $m.s^{-1}$ (Skoufas *et al.*, 2004) and 16.85±1.58 $m.s^{-1}$ (Bayos and Boudolos, 1998). In our study, the sample is heterogeneous (from local level to high national level). Taking into account this heterogeneity, the values obtained in our study logically correspond to an intermediate performance level.

Anthropometric parameters

In accordance with previous studies (Skoufas *et al.*, 2004; Van den Tillaar & Ettema, 2004b; Vila *et al.*, 2009; Zapartidis *et al.*, 2009), we found positive correlations between ball velocity and general anthropometric parameters, with correlation coefficients ranging from .55 to .70. Among all these factors, body mass appears to have the highest correlation to throwing velocity (r=.70). This is in accordance with the literature on this topic in which correlation coefficients ranged from .23 to .62. Our correlations are very close to those found by Van den Tillar and Ettema (2004b) with a second and third national division sample of Norwegian players. The high correlation obtained between body mass and throwing velocity could be explained by the higher muscle mass value of heavier players. Indeed, muscle mass is a key factor of strength and power.

According to previous studies (Skoufas *et al.* 2004; Visnapuu & Jürimaë, 2009; Zapartidis *et al.*, 2009), the ball velocity is significantly and positively correlated with all handball-specific parameters (r=.29-37). However, specific anthropometric parameters are less correlated than general ones. Yet, in spite of significant values of correlation coefficients, the total variance percentage accounted for by the anthropometric parameters is low, just 49% for the best predictor (body mass). Such a poor link has been pointed out previously (Visnapuu & Jürimaë, 2009).

Strength and power of upper limbs

Correlation coefficients obtained between recorded variables (force, power and bar velocity at the bench-press; throwing 2 kg MB) ranged from r=.45 (bar velocity at 30% 1-RMBP) to r=.80 (performance in throwing 2 kg MB).

The 1-RMBP was 73.3±14.0 kg. This value is in accordance with those obtained with players of similar levels. Indeed, with elite players, Gorostiaga *et al.* (2005) found 106.9±11.6 kg, and 82.5±14.8 kg with second division players. It is surprising and difficult to explain why Marques *et al.* (2007) found very low values of 68.8±10.0 kg with elite players. The correlation found is r=.55 and is close to the Marques *et al.* (2007) study, who found r=.63. Thus, the ability to lift heavy loads during bench-press seems to be linked to the ability to throw the ball quickly. However, this indicator accounted for just 39% of the total variance.

V_{Ball} has a significant correlation with maximum power (r=.65, p<0.001) and accounted for 42% of the total variance. The maximum power value occurred at 42.5±2.1% of 1-RMBP. In previous studies, the maximal power output occurred at 30-45% load (Izquierdo *et al.*, 2002) or at 30% of peak isometric force (Kaneko *et al.*, 1983). The maximal power values recorded during bench-press are 675.1±188 W. It is difficult to compare our values with others, because power was recorded when it reached its maximum value during our study, while in the others, the value was averaged over the whole movement. For instance, Marques *et al.* (2007) found a value of about 800 W with elite players, and Izquierdo *et al.* (2002) 468±76 W with amateur second division handball players.

On the other hand, the ball velocity has a significant correlation (r=.60; p<.001) with bar velocity at 20 kg, and also with a load representing 30% of the 1-RMBP (r=.45, p=.003). This velocity accounted for just 36% of total variance. Gorostiaga *et al.* (2005) found such a link at the same load percentage (r=0.67-0.71) with amateur and elite players. Thus, movements with high velocity and low or medium force output are more predictive than low-speed movements requiring a high level of force. Indeed, bench-presses at low loads (first to third bar) show better correlations than at higher loads, as regards power and force output. These loads correspond to maximal power output (between 30 and 45 % of 1-RMBP).

Medicine-ball throwing (2 kg) is correlated with the ball velocity, with a higher correlation coefficient (r=0.80) than that obtained with the bench-press, and accounted for 64% of the total variance. This shows that this dynamic power test is closer to the ball throwing movement and is more likely to predict performance than the bench-press. These results show that power is more important than strength, i.e. the player has to develop an intermediate level of force but with high velocity.

Multiple Regression Model

Using a multiple regression analysis, the predictability level increases from 64% with one factor (medicine ball) to 74% with a three-variable combined model. None of the anthropometric models is able to predict the ball velocity with accuracy; confirming that being tall, heavy or having a big arm span or hand span is not sufficient to throw the ball very quickly. Indeed, the best anthropometric model accounts for only 41% of the total variance, which is lower than a single regression model including only medicine-ball performance. By combining the results obtained with isotonic tests (medicine-ball performance and two bench-press indicators: maximal power and force output on the first bar) the predictability increases to 67%. This proves once more that isotonic tests are more predictive of ball velocity, using a multi-segmental movement, which requires a high level of strength or power in the upper limbs.

Lastly, the model combining the best isotonic test predictor (throwing 2 kg MB) and anthropometric measurements (body mass) accounts for 72.76% of the total variance. In this model, 2 kg MB contributes 67% and body mass contributes 33% of the ball velocity. With three variables, the best model accounts for 74.28% of the total variance. This model includes medicine-ball performance, body mass and force output at 20 kg, with a relative contribution of 48%, 36% and 16% respectively.

However, our models do not account for 26% of the variance. This could be explained by the complexity of the ball-throwing movement. Indeed, it is a complex multi-joint movement (Van den Tillar & Ettema, 2007) requiring a proximal to distal kinetic chain, in which a powerful torsion movement is necessary. In our point of view, the variance percentage for which our model didn't account likely includes two main aspects of the ball-throwing movement. First, neither of these strength tests necessitates a high level of trunk rotator isotonic strength and recruitment of the trunk muscles during axial rotation, as the ball-throwing movement does. Indeed, the bench-press and the medicine-ball throwing require only trunk isometric strength to control balance during the movement. This argument is confirmed by a recent 3-D analysis of the over-arm throw (Van den Tillar & Ettema, 2007) which demonstrated that a pelvic rotation occurred earlier in faster throws than in slower ones, and so necessitated a high trunk muscle isotonic activation level. A recent study suggested using a side medicine-ball throw to solicit high trunk muscles (Ikeda, Kijima, Kawabata, Fuchimoto & Ito, 2007) rather than a backward movement. Lastly, the ball is accelerated over a distance that depends on the movement's amplitude, involving anthropometric parameters but also rapid internal shoulder rotation (Van Den Tillaar & Ettema, 2007), which necessitates good flexibility. The level of shoulder internal rotation at ball release shows a significant relationship with throwing performance (Van Den Tillaar & Ettema, 2007). None of our tests involves such a shoulder rotation. During bench-press, the arms are in front of the trunk, and during the medicine-ball test, the rotation is reduced since the player throws the ball with both hands.

multiple-regression equation applicability

In order to validate the model applicability, we tested a twelve-player independent sample with the combined Model 1 (BM and 2kg MB). The characteristics of the sample and the results are presented in Table 6. In order to do that, we calculated the multiple-regression equation for this new sample and we compared each variable within the equation with our theoretical model (paired T-test). The new equation for combined model 1 is V=0.068BM+0.810(2Kg MB) + 9.2 and is very close to the one found in our study [V=0.081BM+0.817(2Kg MB) + 7.4]. The T-test between observed and predicted variables of both equations showed no difference ($T<1$, n.s. for 2kg MB; $T=1.23$, $p=0.2$ for BM and $T<1$ for the Y-intercept). So, the coefficients values in the equation found are very stable, whatever the sample. This implies that the equation could help trainers, athletes and professionals to detect future talents or to test athletes' current fitness levels.

*****Insert Table 6 about here*****

To conclude, our study shows clearly that 1) medicine-ball (2 kg) throwing is more likely to predict standing ball throwing velocity than anthropometric parameters; 2) general anthropometric parameters are better predictors than specific parameters; and 3) the multiple regression model combining anthropometric parameters and isotonic tests accounts for 72-74% of the ball throwing velocity from a standing position.

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Figure Legends

Figure 1: Example of a typical force, velocity and power evolution with the mass at each bar during the bench-press. The squares represent the velocity, the circles the power and the triangles the force. For this subject, the regression line of velocity assesses a one-repetition maximum at 71 Kg.

Figure 2: relationship between ball throwing velocity and body mass

Figure 3: relationship between ball throwing velocity and arm span

Figure 4: relationship between ball throwing velocity and 2kg-medicine ball throwing

Table 1 Age and training: characteristics of the participants

			Age (y)		Training time (y)		Training per week (n)
		n	m	sd	m	sd	
Level	High national	12	24.1	3.5	14.7	4.4	4
	High Regional	17	20.5	1.9	8.00	4.07	2,7
	Local	13	19.2	1.3	4.62	2.93	2,2
Total		42	21.1	3.0	8.86	5.48	2.92

n :number of participants, m : mean values, sd: standard deviation

Table 2 Correlation between throwing velocity and general anthropometric parameters

Variables	m	sd	Min	Max	CV (%)	LOA -95%	LOA +95%	r	p
Body mass (kg)	78.3	11.3	63.3	109	13.5	74.21	80.99	.70	<.001
Body height (m)	1.812	0.074	1.691	2.022	4	1.789	1.832	.55	<.001
Lean mass (kg)	34.4	3.1	29.97	43.06	9.1	33.63	35.66	.68	<.001
BMI ($kg.m^{-2}$)	23.5	2.4	18.62	28.51	10.5	22.64	24.12	.60	<.001

CV : coefficient of variation in percentage, LOA: limits of agreement.

Table 3 Correlation between throwing velocity and handball specific anthropometric parameters

Variables	m	sd	Min	Max	CV (%)	LOA -95%	LOA +95%	r	p
Hand perimeter (m)	0.5855	0.0323	0.524	0.701	5.8	0.5746	0.5938	.45	.003
Finger span (m)	0.21155	0.0148	0.188	0.254	7.2	0.207	0.2159	.35	.023
Ring finger length (m)	0.1849	0.0109	0.168	0.225	6	0.1813	0.1877	.47	.002
Middle finger length (m)	0.1946	0.0104	0.178	0.236	5.4	0.1908	0.197	.47	.002
Arm span (m)	1.853	0.088	1.681	2.153	4.8	1.825	1.877	.51	<.001

Table 4 Correlation between throwing velocity and isotonic tests

Variables	m	sd	Min	Max	CV (%)	LOA -95%	LOA +95%	r	p
1-RMBP (kg)	73.3	14.0	49	106	12.1	69.8	78.8	.55	<.001
Force at the first bar_{20kg} (N)	410	49.5	294	538	12.1	394	427	.63	<.001
Power max (W)	675.1	188.2	340	1138	13.2	619.2	742.5	.65	<.001
P_{20kg} (W)	625.7	160.8	320	1046	12.5	577.3	682.5	.65	<.001
Bar velocity at 30% 1-RMBP ($m.s^{-1}$)	2.02	0.20	1.45	2.37	10.1	1.96	2.17	.45	.003
V_{20kg} ($m.s^{-1}$)	2.09	0.32	1.38	2.80	15.3	1.99	2.19	.60	<.001
Throwing 2Kg MB (m)	9.720	1.83	6.84	13.22	14.1	9.10	10.18	.80	<.001
Throwing-ball velocity ($m.s^{-1}$)	21.70	2.53	15.78	26.50	10.1	21.02	23.01		

m : mean values, sd: standard deviation, Min: minimum value, Max: maximum value, CV : coefficient of variation , LOA : limits of agreement

Table 5 Multiple regression model predicting ball-throwing velocity

Models	variables	Equation	r	r²	p	Error terms
General anthropometric	BM,HEIGHT, BL, BMI	V= 0.32BM + 0.18HEIGHT – 1.14BL + 0.33BMI – 4.44	.72	.53	<.00001	1.83 $m.s^{-1}$
Handball specific anthropometric	HP, FS, RFL, MFL,AS	V= -142HP + 23FS + 24MFL + 18.6RFL + 11.2AS - 14.2	.60	.36	=.00503	2.16 $m.s^{-1}$
Physical Fitness Tests 1	2Kg MB, P_{20kg}, F_{20kg}	V=0.9(2Kg MB) + 0.0051P_{20kg} - 0.00568 F_{20kg} +11.88	.82	.67	<.00001	1.51 $m.s^{-1}$
Combined Model 1	BM, 2Kg MB,	V=0.081BM+0.817(2Kg MB) + 7.4	.85	.73	<.00001	1.35 $m.s^{-1}$
Combined Model 2	BM, 2Kg MB, F_{20kg},	V=0.08BM + 0.671(2Kg MB) + 0.0085F_{20kg} + 5.48	.86	.74	<.00001	1.33 $m.s^{-1}$

V= Maximal ball throwing velocity, BM: Body mass, AS: Arm span, HP= hand perimeter, FS= Finger Span, RFL= ring finger length,; MFL= middle finger length; 2Kg MB=Medicine ball Throwing, P_{max}= Maximal power during Bench press, V_{20kg}= velocity at the first bar (20 kg) during bench press, P_{20kg}= Power at the first bar (20 kg), RMBP= maximal one repetition bench press, F_{20kg}= force at the first bar (20 kg) during bench press

Table 6 Characteristics and results of the independent sample (n=12)

Variables	m	sd	Min	Max
Age	18.67	1.07	17	21
Training time (Y)	5.75	2.80	1	10
Body height (m)	1.79	0.07	1.68	1.97
Body mass (kg)	72.2	7.4	64	92
BMI (kg.m-2)	22.60	1.52	19.84	24.82
Throwing 2Kg MB (m)	9.65	1.62	6.4	12.2
Throwing-ball velocity ($m.s^{-1}$)	22.19	1.74	26.11	19.41