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

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Abstract

The aims of this study were to (1) investigate the influence of general anthropometric variables, handball-specific anthropometric variables, and upper-limb power and strength on ball-throwing velocity in a standing position (v_{ball}), and (2) predict this velocity using multiple regression methods. Forty-two skilled male handball players (age 21.0 ± 3.0 years; height = 1.81 ± 0.07 m; body mass = 78.3 ± 11.3 kg) participated in the study. We measured general anthropometric variables (height, body mass, lean mass, body mass index) and handball-specific anthropometric parameters (hand size, arm span). Upper-limb dynamic strength was assessed using a medicine ball (2 kg) throwing test, and power using a one-repetition maximum bench-press test. All the variables studied were correlated with ball velocity. Medicine ball throwing performance was the best predictor ($r = 0.80$). General anthropometric variables were better predictors ($r = 0.55$–0.70) than handball-specific anthropometric variables ($r = 0.35$–0.51). The best multiple regression model accounted for 74% of the total variance and included body mass, medicine ball throwing performance, and power output in the 20-kg bench press. The equation formulated could help trainers, athletes, and professionals detect future talent and test athletes' current fitness.

Keywords: *Power, strength, upper limb, bench press*

Introduction

Ball-throwing velocity (v_{ball}) is an important factor in handball (e.g. Gorostiaga, Granados, Ibanez, Gonzalez-Badillo, & Izquierdo, 2006; Gorostiaga, Izquierdo, Iturralde, Ruesta, & Ibanez, 1999; Hoff & Almasbakk, 1995). This velocity depends primarily on the player's ability to accelerate the ball with an overarm throw. Shoulder internal rotation and elbow extension are two important variables (e.g. Fradet et al., 2004; Van den Tillaar & Ettema, 2004a, 2007). Other performance variables 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 velocity of the ball. We investigated three ways of doing this.

First, the height of an individual affects the outcome of physical tests (Åstrand & Rodahl, 1986; Jaric, 2003; McMahon, 1984). Thus anthropometric variables should be taken into account for prediction. Indeed, several studies have shown significant and positive correlations between ball velocity and general anthropometric variables ($r = 0.23$–0.62): body mass, lean body mass, height, and body mass index (BMI) (e.g. Skoufas, Katzamanidis, Hatzikotoylas, Bebetsos, & Patikas, 2004; Van den Tillaar & Ettema, 2004b; Vila et al., 2009; Zapartidis et al., 2009). Other researchers considered anthropometric parameters specific to handball (hand size and arm span) and reported significant and positive correlations ($r = 0.29$–0.37) with ball velocity (Skoufas et al., 2004; Zapartidis et al., 2009). However, although general and specific anthropometric parameters appear to be related to ball velocity, they have low predictability. Moreover, in all of these studies, general anthropometric variables were better predictors than those specific to handball.

Second, 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 in handball, isotonic tests appear to be the most appropriate (Fleck et al., 1992; Marques, Van den Tillaar, Vescovi, & Gonzalez-Badillo, 2007). The bench-press test has

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been used for power and strength assessment in male handball players to predict ball velocity, with positive and significant correlations with one-repetition maximum (1-RM) bench-press strength ($r = 0.63$; Marques et al., 2007) and with bar velocity ($r = 0.67$–0.71) with lower loads (Gorostiaga, Granados, Ibanez, & Izquierdo, 2005; Marques et al., 2007). This shows that upper-limb strength and power tests are related to ball velocity, with stronger correlations with velocity than anthropometric variables. To find a more accurate strength test, closer to overarm throwing kinematics, Pineau and colleagues (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 handball players.

Finally, few studies have combined 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 variables, 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.

Thus, general, hand-specific anthropometric parameters and upper-limb strength tests are linked to throwing velocity. However, none of the above studies was able to predict throwing velocity accurately, using a simple correlation. Thus the aims of this study were to (1) investigate the influence of general anthropometric variables, handball-specific anthropometric variables, and upper-limb power and strength on ball-throwing velocity in a standing position, and (2) predict this velocity using multiple regression methods.

Methods

Experimental approach to the problem

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

Participants

Forty-two skilled male handball players (Table I) participated in the study. The sample consisted of athletes playing at three different levels in the French championship (local, high regional, and high national, corresponding to the third, sixth, and ninth division respectively). All players had at least 2 years of competitive experience and trained at least twice a week. They were all in good physical condition, with no injuries or disabilities. Each participant provided written informed consent after receiving an oral and written explanation of the procedures and the risks and benefits of participating in the study. The study received approval from the university's ethics committee.

Procedures

First, we measured each participant's height, body mass, arm span, and handball-specific variables. Then, after a 5-min warm-up, participants performed a series of medicine-ball throws. After a 30-min rest, they performed a series of five throws of the ball recorded using a radar gun. The best three performances (maximum velocity) were recorded 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.

Table I. Age and training characteristics of the participants.

Level	No. of participants	Age (years)		Training time (years)		Training sessions per week (n)
		mean	s	mean	s	
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

Anthropometric parameters. We followed the standardized techniques recommended by the International Society for the Advancement of Kinanthropometry (Marfell-Jones, Olds, Stewart, & Carter, 2006). Height and arm span were measured using an anthropometer, with 0.1 cm accuracy. Body mass was measured using bioelectric 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 conducted twice separated by 1 h to calculate measurement reliability. The intra-class correlation coefficient was 98%.

Upper-limb strength and power. Available data suggest 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 (Katic, Cavala, & Srhoj, 2007; Pineau et al., 1989, 1992). In this test, participants were instructed to throw a medicine ball (mass 2 kg, circumference 56 cm) as far as they could, 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 participant performed five trials with a 1-min rest between trials. The best two performances were recorded and averaged for further analysis. The intra-class correlation coefficient was 95%. A soft mat was rolled out on the floor, on which the point at which the medicine ball landed could easily be located and measured with a 20-m tape measure to 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 provided the next increment. When the velocity became too slow (less than 100 cm $\cdot$ s^{-1}), 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 following day. All participants met these criteria.

Throwing velocity. Ball velocity was evaluated by an overarm throw in a standing (i.e. stationary) position, with both feet on the ground as for penalty throws. After a 10-min warm-up, the participant was instructed to throw a standard handball (mass 0.48 kg, circumference 58 cm) at maximal velocity

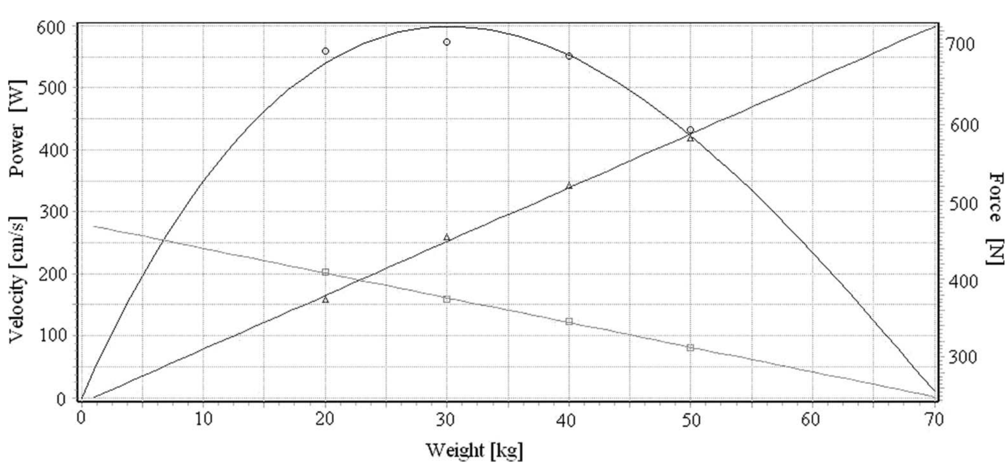

Figure 1. Example of the typical evolution of force, velocity, and power with mass at each bar during the bench press. The squares represent the velocity, the circles the power, and the triangles the force. For this participant, the regression line of velocity assesses a one-repetition maximum at 71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

at a 0.5×0.5 m target located in the middle of a standard handball goal (2×3 m) located 7 m away. No advice was given regarding throwing technique. Each participant performed five trials with a 1-min rest between trials. The best three performances were recorded 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. Ball velocity was recorded using a Doppler-radar gun (MATSPORT TRAINING, Radar ATS) with a frequency of 250 Hz and ± 0.027 m $\cdot$ s^{-1} accuracy. The radar gun was placed 3 m behind the player, in the thrower–target axis at a height corresponding to the player's height. To be as accurate as possible, only throws hitting the target were recorded for further analysis. The intra-class correlation coefficient was 95%.

Statistical analyses

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

$$Y = b_1x_1 + b_2x_2\, b_3x_3 + b_4$$

where Y, the dependent variable, representing ball velocity, is normally distributed, x_i is the i^{th} predictor, and b_i is the coefficient. Descriptive statistics were used to verify that the basic dependent variable assumption of normality was met. Distribution normality tests and skewness revealed no abnormal pattern to the data. For each variable, the 95% limits of agreement (LOA) and coefficient of variation (CV) were calculated (Atkinson & Nevill, 1998). In addition, to validate the applicability of the multiple regression equation, using the same protocol, we tested a 12-player independent sample (skilled handball players studying in the authors' university's sport science department) using Howell's (2010) method. 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). An alpha of 0.05 was used for all statistical tests.

Results

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

Anthropometric parameters

Mean, minimum, and maximum values together with correlations are summarized in Tables II and III. All general anthropometric variables (body mass, lean mass, body height, BMI) were correlated with throwing velocity ($r > 0.55$; $P < 0.001$). The *r*-values ranged from 0.55 (height) to 0.70 (body mass) (Figure 2). The handball-specific anthropometric variables were also correlated with ball velocity but more weakly (Figure 3) than the general anthropometric variables (Table III). The *r*-values ranged from 0.35 (finger span) to 0.51 (arm span).

Isotonic tests

The results of the isotonic are summarized in Table IV. Mean 1-RM bench press was 73.3 ± 14.0 kg (range 49–106 kg) and was strongly

Table II. Correlations between throwing velocity and general anthropometric parameters.

Variables	mean	*s*	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	0.70	<0.001
Height (m)	1.812	0.074	1.691	2.022	4.0	1.789	1.832	0.55	<0.001
Lean mass (kg)	34.4	3.1	29.97	43.06	9.1	33.63	35.66	0.68	<0.001
BMI (kg $\cdot$ m^{-2})	23.5	2.4	18.62	28.51	10.5	22.64	24.12	0.60	<0.001

Note: CV = coefficient of variation as a percentage, LOA = limits of agreement.

Table III. Correlations between throwing velocity and handball-specific anthropometric parameters.

Variables	mean	*s*	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	0.45	0.003
Finger span (m)	0.21155	0.0148	0.188	0.254	7.2	0.207	0.2159	0.35	0.023
Ring finger length (m)	0.1849	0.0109	0.168	0.225	6.0	0.1813	0.1877	0.47	0.002
Middle finger length (m)	0.1946	0.0104	0.178	0.236	5.4	0.1908	0.197	0.47	0.002
Arm span (m)	1.853	0.088	1.681	2.153	4.8	1.825	1.877	0.51	<0.001

Note: CV = coefficient of variation as a percentage, LOA = limits of agreement.

correlated with ball velocity ($r = 0.55$; $P < 0.001$). Force output during the first bar was 410 ± 49.5 N (range 294–538 N) and was strongly correlated with ball velocity ($r = 0.63$; $P < 0.001$). Mean maximum power was 675.1 ± 188 W and was obtained at an average load corresponding to 42.5% of the 1-RM bench press value; it ranged from 340 to 1138 W and was strongly correlated with ball velocity ($r = 0.65$; $P < 0.001$). The power output at the first bar was

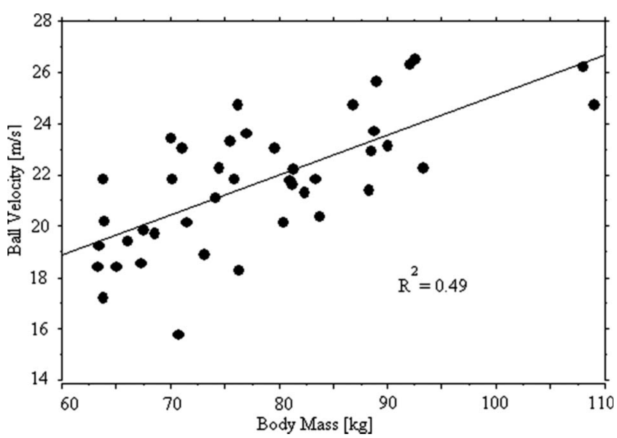

Figure 2. Relationship between ball throwing velocity and body mass.

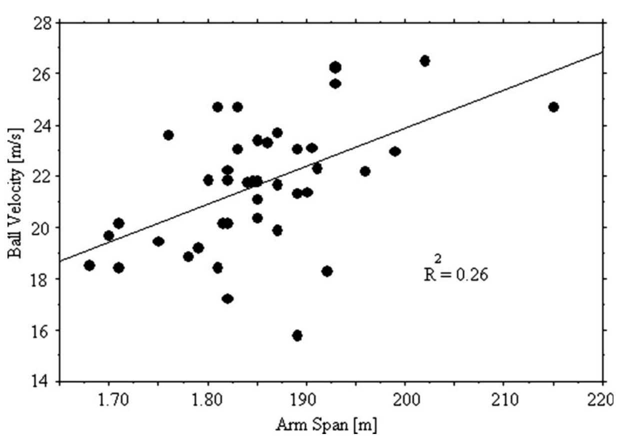

Figure 3. Relationship between ball throwing velocity and arm span.

625.7 ± 160.8 W (range 320–1046 W) and was strongly correlated with ball velocity ($r = 0.65$; $P < 0.001$). The velocity of the bar at 20 kg was 2.09 ± 0.32 m $\cdot$ s^{-1} (range 1.38–2.80 m $\cdot$ s^{-1}) and was strongly correlated with ball velocity ($r = 0.59$; $P < 0.001$). The bar velocity at a load corresponding to 30% of 1-RM bench press was 2.025 ± 0.21 m $\cdot$ s^{-1} (range 1.45–2.37 m $\cdot$ s^{-1}) and was strongly correlated with ball velocity ($r = 0.45$; $P = 0.003$).

Mean throwing mean performance with the 2-kg medicine ball was 9.72 ± 1.8 m (range 6.84–13.22 m) (Figure 4). This isotonic test was highly correlated with ball velocity ($r = 0.80$; $P < 0.001$).

Multiple regression model

We tested all the models with parameters included that correlated strongly with ball velocity. The best ones are summarized in Table V and classified into 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). Second, the best handball-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. Third, the best physical fitness model 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. Finally, combining the anthropometric and physical fitness parameters, two models were retained with correlation coefficients of 0.85 and 0.86 ($P < 0.00001$), accounting for 72% and 74% of the total variance respectively. The error terms were 1.33 m $\cdot$ s^{-1} and 1.35 m $\cdot$ s^{-1} respectively. These models included body mass, medicine-ball throwing performance, and either force output at 20-kg bench-press or 1-RM bench press.

Table IV. Correlations between throwing velocity and isotonic tests.

Variables	mean	*s*	min.	max.	CV (%)	LOA −95%	LOA +95%	*r*	*P*
1-RM bench press (kg)	73.3	14.0	49	106	12.1	69.8	78.8	0.55	<0.001
Force at the first bar$_{20kg}$ (N)	410	49.5	294	538	12.1	394	427	0.63	<0.001
Maximum power (W)	675.1	188.2	340	1138	13.2	619.2	742.5	0.65	<.001
Power$_{20kg}$ (W)	625.7	160.8	320	1046	12.5	577.3	682.5	0.65	<0.001
Bar velocity at 30% 1-RM bench press (m $\cdot$ s^{-1})	2.02	0.20	1.45	2.37	10.1	1.96	2.17	0.45	0.003
v_{20kg} (m.s^{-1})	2.09	0.32	1.38	2.80	15.3	1.99	2.19	0.60	<0.001
Throwing distance (m)	9.720	1.83	6.84	13.22	14.1	9.10	10.18	0.80	<0.001
Throwing velocity (m $\cdot$ s^{-1})	21.70	2.53	15.78	26.50	10.1	21.02	23.01		

Note: CV = coefficient of variation as a percentage, LOA = limits of agreement.

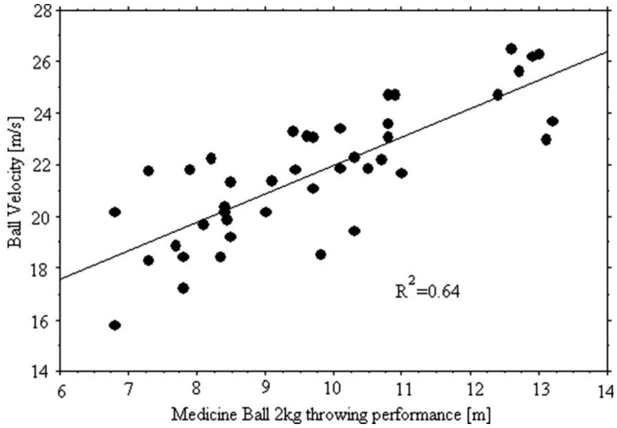

Figure 4. Relationship between ball throwing velocity and 2-kg medicine-ball throwing performance.

Discussion

In this study, we examined the effect of general and specific anthropometric variables 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 line with those for other adult male samples of elite handball players: 23.8 ± 1.9 m · s^{-1} (Gorostiaga, Granados, Ibanez, & Izquierdo, 2005), 24.45 ± 1.97 m · s^{-1} (Wit & Eliasz, 1998), and 23.51 ± 2.23 m · s^{-1} (Bayios & Boudolos, 1998). For experienced handball players, playing in the second and/or third division, standing throwing velocity was reported to be 23.2 ± 1.6 m · s^{-1} (Van den Tillaar & Ettema, 2004b) and 21.8 ± 1.6 m · s^{-1} (Gorostiaga et al., 2005). For novice handball players and 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} (Bayios & Boudolos, 1998) respectively. In the present study, the sample was heterogeneous (from local level to high national level). Taking into account this heterogeneity, the values obtained in our study logically correspond to an intermediate level of performance.

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 0.55 to 0.70. Among these factors, body mass appears to have the strongest correlation with throwing velocity ($r = 0.70$). This is in accordance with the literature on this topic, with correlation coefficients ranging from 0.23 to 0.62. Our correlations are very similar to those reported by Van den Tillaar and Ettema (2004b) for Norwegian

Table V. Multiple regression model predicting ball-throwing velocity.

Models	Variables	Equation	r	r^2	P	Error terms
General anthropometric	BM, HEIGHT, BL, BMI	$v = 0.32BM + 0.18HEIGHT - 1.14BL + 0.33BMI - 4.44$	0.72	0.53	<0.00001	1.83 m · s^{-1}
Handball-specific anthropometric	HP, FS, RFL, MFL, AS	$v = -142HP + 23FS + 24MFL + 18.6RFL + 11.2AS - 14.2$	0.60	0.36	0.00503	2.16 m · s^{-1}
Physical fitness tests 1	2kg MB, P_{20kg}, F_{20kg}	$v = 0.9(2kg\ MB) + 0.0051P_{20kg} - 0.00568F_{20kg} + 11.88$	0.82	0.67	<0.00001	1.51 m · s^{-1}
Combined Model 1	BM, 2kg MB	$v = 0.081BM + 0.817(2kg\ MB) + 7.4$	0.85	0.73	<0.00001	1.35 m · s^{-1}
Combined Model 2	BM, 2kg MB, F_{20kg}	$v = 0.08BM + 0.671(2kg\ MB) + 0.0085F_{20kg} + 5.48$	0.86	0.74	<0.00001	1.33 m · s^{-1}

Note: 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 distance, P_{max} = maximal power during bench press, P_{20kg} = power at the first bar (20 kg), F_{20kg} = force at the first bar (20 kg) during bench press.

second and third division players. The high correlation obtained between body mass and throwing velocity could be explained by the greater muscle mass of heavier players. Indeed, muscle mass is a key factor of strength and power.

In previous studies (Skoufas et al. 2004; Visnapuu & Jürimaë, 2009; Zapartidis et al., 2009), ball velocity was reported to be significantly and positively correlated with all handball-specific parameters ($r = 0.29$–0.37). However, handball-specific anthropometric parameters were less well correlated than general anthropometric parameters with ball velocity. Yet, in spite of significant correlation coefficients, the total percent variance accounted for by the anthropometric parameters was low, just 49% for the best predictor (body mass). Such a poor link has been highlighted previously (Visnapuu & Jürimaë, 2009).

Strength and power of upper limbs

Correlation coefficients obtained between recorded variables (force, power, and bar velocity in the bench press; medicine-ball throwing performance) ranged from $r = 0.45$ (bar velocity at 30% 1-RM bench press) to $r = 0.80$ (medicine-ball throwing performance).

The 1-RM bench press was 73.3 ± 14.0 kg. This value is in accordance with those obtained previously with players of similar standard. Indeed, Gorostiaga et al. (2005) reported 106.9 ± 11.6 kg for elite players and 82.5 ± 14.8 kg for second division players. It is surprising and difficult to explain why Marques et al. (2007) reported such low values (68.8 ± 10.0 kg) for elite players. The correlation between mean 1-RM bench press and ball velocity in the present study was $r = 0.55$ and is close to that reported by Marques et al. (2007), $r = 0.63$. Thus, the ability to lift heavy loads during the 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.

Ball velocity was strongly correlated with maximum power ($r = 0.65$, $P < 0.001$) and accounted for 42% of the total variance. Maximum power occurred at 42.5 ± 2.1% of 1-RM bench press. In previous studies, maximum power output occurred at 30–45% load (Izquierdo, Häkkinen, Gonzalez-Badillo, Ibáñez, & Gorostiaga, 2002) or at 30% of peak isometric force (Kaneko, Fuchimoto, Toji, & Suei, 1983). Maximum power recorded during the bench press was 675.1 ± 188 W. It is difficult to compare our values with those of others, because power was recorded when it reached its maximum during our study, whereas in others the value was averaged over the whole movement. For instance, Marques et al. (2007) reported a value of about 800 W with elite players, and Izquierdo et al. (2002) reported 468 ± 76 W with amateur second division handball players.

Ball velocity was strongly correlated ($r = 0.60$; $P < 0.001$) with bar velocity at 20 kg, and also with the load corresponding to 30% of 1-RM bench press ($r = 0.45$; $P = 0.003$). This velocity accounted for just 36% of total variance. Gorostiaga et al. (2005) found such a link at the same percentage load ($r = 0.67$–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, in terms of power and force output. These loads correspond to maximal power output (between 30 and 45% of 1-RM bench press).

Throwing of a 2-kg medicine ball was correlated with 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, predictability increases from 64% with one variable (medicine ball) to 74% with a model combining three variables. None of the anthropometric models is able to predict ball velocity with accuracy; confirming that being tall, heavy or having a wide 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 with only medicine-ball throwing performance. By combining the results obtained with isotonic tests (medicine-ball throwing performance and two bench-press indicators: maximal power and force output on the first bar) the predictability increases to 67%. This shows 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.

Finally, the model combining the best isotonic test predictor (medicine-ball throwing performance) and anthropometric measurement (body mass) accounts for 72.76% of the total variance. In this model, medicine-ball throwing performance contributes 67% and body mass contributes 33% of variance in 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 relative contributions 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 Tillaar & Ettema, 2007) requiring a proximal-to-distal kinetic chain, in which a powerful torsion movement is necessary. In our view, the 26% of the variance for which our model does not account likely includes two main aspects of the ball-throwing movement. First, neither of these strength tests requires a high level of trunk rotator isotonic strength and recruitment of the trunk muscles during axial rotation, in the way the ball-throwing movement does. Indeed, the bench press and the medicine-ball throw require only trunk isometric strength to control balance during the movement. This argument is confirmed by a recent three-dimensional analysis of the overarm throw (Van den Tillaar & Ettema, 2007), which demonstrated that a pelvic rotation occurred earlier in faster throws than in slower ones, and so required greater trunk muscle isotonic activation. 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 requires 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 involved such a shoulder rotation. During the 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.

Applicability of multiple-regression equation

To assess the applicability of the model, we tested a 12-player independent sample with the combined Model 1 (body mass and medicine-ball throwing performance). The characteristics of the sample and the results are presented in Table VI. 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 $v = 0.068\text{BM} + 0.810(\text{MB}) + 9.2$ and is very close to that found in our study [$v = 0.081\text{BM} + 0.817(\text{MB}) + 7.4$], where BM = body mass and MB = 2-kg medicine-ball

Table VI. Characteristics and results of the independent sample ($n = 12$).

Variables	mean	s	min.	max.
Age	18.67	1.07	17	21
Training experience (years)	5.75	2.80	1	10
Height (m)	1.79	0.07	1.68	1.97
Body mass (kg)	72.2	7.4	64	92
BMI ($\text{kg} \cdot \text{m}^{-2}$)	22.60	1.52	19.84	24.82
Throwing distance (m)	9.65	1.62	6.4	12.2
Throwing velocity ($\text{m} \cdot \text{s}^{-1}$)	22.19	1.74	26.11	19.41

throwing performance. The *t*-test between observed and predicted variables of both equations showed no difference ($t < 1$, N.S. for medicine ball; $t = 1.23$, $P = 0.2$ for body mass; and $t < 1$ for the *y*-intercept). So, the coefficients in the equation found are very stable, whatever the sample. This implies that the equation could help trainers, athletes, and professionals to detect future talent or to test athletes' current fitness.

In conclusion, our results show that: (1) 2-kg medicine-ball throwing performance is more likely to predict standing ball throwing velocity than anthropometric parameters; (2) general anthropometric variables are better predictors of ball velocity than handball-specific variables; and (3) the multiple regression model combining anthropometric variables and isotonic tests accounts for 72–74% of ball throwing velocity from a standing position.

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