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Differences in Physical Fitness and Throwing Velocity Among Elite and Amateur Male Handball Players

Abstract

This study compared physical characteristics (body height, body mass [BM], body fat [BF], and free fatty mass [FFM]), one repetition maximum bench-press ($1RM_{BP}$), jumping explosive strength (VJ), handball throwing velocity, power-load relationship of the leg and arm extensor muscles, 5- and 15-m sprint running time, and running endurance in two handball male teams: elite team, one of the world's leading teams (EM, $n = 15$) and amateur team, playing in the Spanish National Second Division (AM, $n = 15$). EM had similar values in body height, BF, VJ, 5- and 15-m sprint running time and running endurance than AM. However, the EM group gave higher values in BM (95.2 ± 13 kg vs. 82.4 ± 10 kg, $p < 0.05$), FFM (81.7 ± 9 kg vs. 72.4 ± 7 kg, $p < 0.05$), $1RM_{BP}$ (107 ± 12 kg vs. 83 ± 10 kg, $p < 0.001$), muscle power during bench-press (18 – 21 %, $p < 0.05$) and half squat (13 – 17 %), and throwing velocities at standing ($23.8 \pm 1.9\ m \cdot s^{-1}$ vs. $21.8 \pm 1.6\ m \cdot s^{-1}$, $p < 0.05$) and 3-step running ($25.3 \pm 2.2\ m \cdot s^{-1}$ vs. $22.9 \pm 1.4\ m \cdot s^{-1}$, $p < 0.05$) actions than the AM group. Significant correlations ($r = 0.67 – 0.71$, $p < 0.05 – 0.01$) were observed in EM and AM between individual values of velocity at 30 % of $1RM_{BP}$ and individual values of ball velocity during a standing throw. Significant correlations were observed in EM, but not in AM, between the individual values of velocity during 3-step running throw and the individual values of velocity at 30 % of $1RM_{BP}$ ($r = 0.72$, $p < 0.05$), as well as the individual values of power at 100 % of body mass during half-squat actions ($r = 0.62$, $p < 0.05$). The present results suggest that more muscular and powerful players are at an advantage in handball. The differences observed in free fatty mass could partly explain the differences observed between groups in absolute maximal strength and muscle power. In EM, higher efficiency in handball throwing velocity may be associated with both upper and lower extremity power output capabilities, whereas in AM this relationship may be different. Endurance capacity does not seem to represent a limitation for elite performance in handball.

Key words
Muscle strength · muscle power · endurance · arm throwing

Introduction

Handball is a very strenuous body-contact team sport that places heavy emphasis on running, jumping, running speed, and throwing [23], and requires substantial strength levels to hit, block, push, and hold during game actions. From this, it may be hypothesized that high levels of strength and muscle power as well as aerobic capacity should be important for successful participation in elite levels of handball leagues. However, few studies have compared anthropometric and physiological characteristics for handball players of different levels. Although some studies have analysed some physiological characteristics of elite handball players in the 70s and 80s [4,9,10,16], little information is available concerning the physiological and anthropometric characteristics of current world class handball players. Examination of fitness profile could be of great importance for optimal construction of the strength/power and endurance training programs to improve handball performance.

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Table **1** Physical characteristics and training experience of elite male team (EM) and amateur male team (AM)

	Age (years)	*Height (cm)*	*Body mass (kg)*	*Body fat (%)*	*Free fatty mass (kg)*	*Training experience (years)*
Elite male players (n = 15)	31.0 (3)[a]	188.7 (8)	95.2 (13)[a]	13.8 (2)	81.7 (9)[a]	20.2 (4)[a]
Amateur male players (n = 15)	22.2 (4)	183.8 (7)	82.4 (10)	11.6 (3)	72.4 (7)	11.4 (3)

[a] Significant difference ($p < 0.05$) compared to amateur male handball players. Results are means (± SD)

Although handball players require superior levels of physical skills that include jumping, diving, blocking, sprinting, ball control, and agility, one of the most important skills for success in team handball is throwing ability. The combination of ball velocity and accuracy at throwing is one of the most important factors which has a decisive effect on scoring, because the faster and more accurately the ball can be thrown at the goal the less time defenders and goalkeepers have to parry it [17]. Three basic factors are important with regard to the efficiency of arm throwing [13,17]: the throwing technique, the timing of the consecutive actions of body segments, and upper and lower-extremity muscle strength and power. Two studies have found that muscle strength is an important factor influencing throwing handball velocity in elite male handball players because they have reported significant relationships between throwing velocity and elbow extension isokinetic torque [9] as well as with maximal isometric hand grip strength [16]. However, the isokinetic and isometric tests do not reflect the “natural” movements of the limbs involved during handball. Tests employing free barbells reflect the functional strength of the handball player more accurately, as well as being readily available to most teams. To the authors’ knowledge no studies have reported the relationships between handball ball velocity and the power output generated during muscle contractions of the lower and upper-extremity muscles in concentric isotonic actions (i. e. bench-press and half squat exercises). Further, it is not known if these relationships are different in elite as opposed to amateur handball players.

Considering that handball places heavy emphasis on maximal strength and muscle power-related actions, the data were collected to test the following hypotheses. First, a difference exists between elite and amateur handball players regarding absolute maximal strength and muscle power development, as well as anthropometric characteristics. Second, some muscle power values of the upper and lower extremities could be related to handball throwing velocity. Therefore, the aim of this study was to investigate what fitness, anthropometric, and specific throwing tests could differentiate between elite and amateur handball players. Secondly, it was also of interest to examine the relationships between selected upper and lower extremity maximal strength and power production, and throwing velocity during standing and 3-step forward shots [9].

Methods

Subjects

Two handball teams participated in the study. According to their competitive level, the subjects were divided into two groups: an elite male team (EM, n = 15; age: 31.0 ± 3 yr) and an amateur male team (AM, n = 15; age: 22,2 ± 4 yr). EM had higher handball training experience (20.2 ± 4 yr) than AM (11.4 ± 3 yr) and can be considered as one of the world’s leading professional handball teams because: 1) the EM team was the current Spanish handball champion, and seven months later it was runner-up in the European Champions League, 2) twelve of their players are or have been internationals and had won 18 Olympic and/or World Championship medals, and 3) European players are the world-leaders in handball because in the last 3 Olympic Games and the last 4 World Handball Championships, the first 5 places have been won by European national teams. AM players played in the National Second Division League and all of them were amateur players. This study was carried out in September, 1 week after the end of the 5- to 7-week pre-competitive mesocycle. During the 5-week pre-competitive mesocycle EM players had an average of 45 training sessions (9 training sessions per week) for a total average duration of 3.208 minutes distributed as follows: endurance training (30%), strength training (28%), speed training (1%), and playing sessions (41%). During the 7-week pre-competitive mesocycle, AM players had an average of 33 training sessions (4.7 training sessions per week) for a total average duration of 2.108 minutes, distributed as follows: endurance training (22%), strength training (28%), and playing sessions (50%). During the whole pre-competitive mesocycle, one player from the EM group and one player from the AM group lost 3 training sessions due to injury. The physical characteristics and handball training background of the subjects are presented in Table **1**.

The subjects and coaches were informed carefully about the experimental procedures and the possible risks and benefits of the project, which was approved by the Institutional Review Committee of the Instituto Navarro de Deporte y Juventud, and carried out according to the Declaration of Helsinki.

Experimental approach to the problem

To determine if anthropometric and physical fitness parameters are different between male handball players of different competitive level, a comparison study was conducted. Two distinct groups of handball players were identified: elite and amateur males. These groups of handball players were tested and compared with an analysis of variance (ANOVA) to determine if anthropometric, physical fitness and throwing velocity parameters distinguished any of the groups. If differences existed, then this would tend to indicate the relative importance of these parameters to progress toward the elite professional rank. All the subjects were familiarized with the testing protocol, as they have been previously tested on several occasions in previous years with the same testing procedures. The test-retest intraclass correlation coefficients of the testing procedure variables used in this study were greater than 0.91, and the coefficients of variation (CV) ranged from 0.9% to 7.3%.

Testing schedule

The subjects were carefully familiarized with the testing protocol, as they had been previously tested on several occasions in previous seasons for training prescription purposes. All of the players within a given team were assessed on the same day, and the tests were performed in the same order. Testing was conducted over three separate sessions separated by at least two days. During the first testing session, each subject was subjected to a sprint and endurance running test. In the second test session, each subject was tested for anthropometrical measurements, maximal and explosive strength, and muscle power. In the third testing session, penalty and 3-step running-throw velocities were measured. Testing was integrated into weekly training schedules.

Physical characteristics

The anthropometric variables of height (m), weight (kg), body fat (%), and free fatty mass (kg) were measured in each subject. Height and weight measurements were made on a levelled platform scale (Año Sayol, Barcelona, Spain) with an accuracy of 0.01 kg and 0.001 m, respectively. Body mass index (BMI) was calculated from body mass and body height ($kg \cdot m^{-2}$). Percentage of body fat was calculated from measurements of skinfold thickness [11]. Free fatty mass (FFM, in kg) was calculated as a difference between body mass and body fat.

Sprint and endurance running test

After a non-standardised 15-min warm-up period that included low-intensity running, several acceleration runs, and stretching exercises, the subjects undertook a sprint running test consisting of three maximal sprints of 15 m, with a 90-s rest period between each sprint, on an indoor court. During the 90 seconds recovery period, the subjects walked back to the starting line. The recording of running time was done using photocell gates (Newtest OY, Oulu, Finland) placed 0.4 m above the ground, with an accuracy of 0.001 s. The subjects commenced the sprint when ready from a standing start, 0.5 m behind the start. Stance for the start was consistent for each subject. The time was automatically activated as the subject passed the first gate at the 0 m mark and split times were recorded at 5 m and 15 m. The run with the lowest time was selected for further analysis.

The endurance running test was performed five minutes after the end of the sprint running test on an indoor court. Each subject performed a four-stage submaximal discontinuous progressive running test around the handball court (40 × 20 m), with a 3-min rest between each run. The running velocities for the four stages were $10\,km \cdot h^{-1}$, $12\,km \cdot h^{-1}$, $14\,km \cdot h^{-1}$, and $16\,km \cdot h^{-1}$. Time for each stage was 5 min. To assure a constant velocity for each running stage, subjects were instructed to even pace their running through an audio signal connected to a pre-programmed computer (Balise Temporelle, Bauman, Switzerland). During the test, heart rate was recorded every 15 s (Sportester Polar, Kempele, Finland) and averaged for the last 60 s of each stage. Immediately after each exercise stage, capillary blood samples for the determination of lactate concentrations were obtained from hyperaemic earlobe. Samples for whole blood lactate determination (100 µl) were deproteinized, stored at 4 °C, and analysed (YSI, 1500 Sport L-Lactate Analyzer, Ohio, USA). The blood lactate analyser was calibrated after every fifth blood sample dose with three known controls (5, 15, and $30\,mmol \cdot l^{-1}$). Individual data points for the exercise blood lactate values were plotted as a continuous function against time. The exercise lactate curve was fitted with a second degree polynomic function. From the equation describing the exercise blood lactate curve, the velocity associated with a blood lactate concentration of $3\,mmol \cdot l^{-1}$ (V_3) was interpolated. The submaximal velocity associated with a given absolute blood lactate concentration has been shown to be an important determinant of endurance performance capacity [24].

Jumping test

The jumping test was performed on an indoor court and consisted of four maximal counter-movements jumps with arms swing on a contact platform (Newtest OY, Oulu, Finland). The subjects were asked to perform a maximal jump on the contact platform from standing position with a preparatory movement from the extended leg position down to the 90-degree knee flexion followed by a subsequent concentric action. Subjects could move their arm freely but were instructed to land on the contact platform in a position similar to that of the take-off. The jumping height was calculated from the flight time [5]. Two sets of two maximal jumps were recorded interspersed with approximately 10-s rest between jumps and 90-s rest between sets. The best reading was used for further analysis.

Maximal strength and muscle power test

A detailed description of the maximal strength and muscle power testing procedure can be found elsewhere [14]. Basically, maximal strength of the upper extremity was assessed using one repetition concentric maximum bench-press action ($1RM_{BP}$). Bench-press (elbow extension) was chosen because it seems most specific to the overhand throwing technique [9]. The test was performed in a squatting apparatus in which the barbell was attached to both ends, with linear bearings on two vertical bars allowing only vertical movements. The bar was positioned 1 cm above the subject's chest and supported by the bottom stops of the measurement device. The subject was instructed to perform a purely concentric action from the starting position, maintaining the shoulders in a 90-degree abducted position to ensure consistency of the shoulder and elbow joints throughout the testing movements [14,19]. No bouncing or arching of the back was allowed. Warm-up consisted of a set of five repetitions at loads of 40 – 60% of the perceived maximum. Thereafter, four to five separate single attempts were performed until the subject was unable to reach the full extension position of the arms. The last acceptable extension with the highest possible load was determined as $1RM_{BP}$. The rest period between attempts was always 2 minutes.

The power-load relationship of the arm and leg extensor muscles was tested in bench-press and half-squat position respectively, using the relative loads of 30%, 45%, 60%, and 70% of 1 RM for bench-press exercise, and 60%, 80% 100%, and 125% of Body Mass (BM) for half-squat exercise. In half-squat position shoulders were in contact with a bar and the starting knee angle was 90 degrees [14]. On command the subject performed a concentric leg extension (as fast as possible) starting from the flexed position to reach the full extension of 180 degrees against the resistance determined by the weight plates added to both ends of the bar. The trunk was kept as straight as possible. The subjects were allowed to use a weight training belt. Warm-up consisted of a set of 5 repetitions at the loads of 40 – 60% of the body mass. Two testing actions were recorded and the best reading (with the best velocity) was taken for further analysis. The time period of rest between each trial and set was always 1.5 minutes.

During the lower and upper extremity test actions, bar displacement, average velocity ($m \cdot s^{-1}$), and mean power (W) were recorded by linking a rotary encoder to the end part of the bar. The rotary encoder recorded the position and direction of the bar within accuracy of 0.0002 m. Customized software (JLML I + D, Madrid, Spain) was used to calculate the power output for each repetition of the half-squat and bench-press performed throughout the whole range of motion. Average power output for each repetition of the half-squat and bench-press was determined. Power curves were plotted using average power over the whole range of movement as a most representative mechanical parameter associated with a contraction cycle of leg and arm extensor muscles participating in the half-squat (i.e. hip, knee, and ankle joints) and bench press (i.e. elbow and shoulder joints) performances. In all neuromuscular performance tests strong verbal encouragement was given to each subject to motivate them to perform each test action as maximally and as rapidly as possible. The reproducibility of the measurements has been reported elsewhere [14].

Handball throwing test

Specific explosive strength production in handball was evaluated on an indoor handball court by an overarm throw, in two situations: a standing throw (penalty throw) and a 3-step running throw. After a 10-minute standardised warming up, the subjects were instructed to throw a standard handball (mass 480 g, circumference 58 cm) as fast as possible through a standard goal, using one hand and their own technique. In the standing throw, one of the feet had to be in contact with the floor behind the line 7 m from the goal (penalty mark); in the 3-step running throw, the players were allowed to do a preparatory run, limited to three regular steps before releasing the ball behind the line 9 m from the goal. The recording of throwing time was done with an accuracy of 0.001 s using photocell gates (Newtest OY, Oulu, Finland) placed on two tripods located parallel to the throwing trajectory, in front of the left post of the goal. The first tripod was located 3.4 m from the penalty mark and contained five vertically distributed photocells (range 1.49 – 2.10 m above the ground). The second tripod was placed 6.4 m from the penalty mark and contained four vertically distributed photocells (range 1.37 – 1.89 m above the ground). To simulate a real handball game action, the players were told to throw to the upper right corner of the goal with maximal velocity and were allowed to put resin on their hands to throw the ball. The time was automatically activated as the handball passed the photocells of the first tripod and was stopped when the handball passed the photocells of the second tripod. Average throwing velocity was calculated from the time and the distance (3 m) covered by the ball. The coaches supervised the entire throwing test to ensure that the subjects were using the right handball technique. For each type of throw, each subject performed trials until three correct throws were recorded, up to a maximum of three sets of three consecutive throws. A 1 – 2-minute rest elapsed between sets of throws and 10 – 15 s elapsed between two throws of the same set. As motivation, athletes were immediately informed of their performance. The throw with the highest average ball velocity was selected for further analysis.

Statistical procedures

Standard statistical methods were used for the calculation of the mean and standard deviations. Pearson product-moment correlation coefficients (r) were used to determine the association between physical characteristics, maximum bench-press ($1RM_{BP}$), jumping explosive strength, handball throwing velocity, power-load relationship of the leg and arm extensor muscles, 5- and 15-m sprint running time, and running endurance. Statistical power calculations for *t*-test correlation ranged from 0.69 to 0.95 in this study. The differences between the two groups for the aforementioned variables were determined using one-way analysis of variance (ANOVA), with Newman-Keuls post hoc comparisons. The $p \leq 0.05$ criterion was used for establishing statistical significance.

Results

Physical characteristics and training experience

The physical characteristics and training handball experience of the handball players are presented in Table **1**. EM team showed higher body mass (13%, $p < 0.05$), free fatty mass (11%, $p < 0.05$), age (29%, $p < 0.001$), and training experience (43%, $p < 0.01$) than AM team. No differences were observed in body height and percent body fat between EM and AM. Body mass index (BMI, $kg \cdot m^{-2}$) in EM was also significantly higher than in AM (8%, $p < 0.05$).

Maximal sprint and endurance running

The results of maximal running sprint and endurance running tests are presented in Table **2**. No difference was observed between the groups in maximal sprint running times for 5 m and 15 m. During the endurance running test, no differences in mean blood lactate concentration were observed in both groups at running velocities of $10\,km \cdot h^{-1}$ ($1.8 \pm 0.5\,mmol \cdot l^{-1}$ and $1.8 \pm 0.4\,mmol \cdot l^{-1}$ for EM and AM, respectively), $12\,km \cdot h^{-1}$ ($3.2 \pm 1.1\,mmol \cdot l^{-1}$ and $2.9 \pm 0.8\,mmol \cdot l^{-1}$ for EM and AM, respectively), and $14\,km \cdot h^{-1}$ ($7.2 \pm 2.0\,mmol \cdot l^{-1}$ and $6.1 \pm 1.5\,mmol \cdot l^{-1}$ for EM and AM, respectively). Similarly, no differences in mean heart rate values were observed in both groups at running velocities of $10\,km \cdot h^{-1}$ (140 ± 8 $beats \cdot min^{-1}$ and 146 ± 8 $beats \cdot min^{-1}$ for EM and AM, respectively), $12\,km \cdot h^{-1}$ (158 ± 7 $beats \cdot min^{-1}$ and 161 ± 7 $beats \cdot min^{-1}$ for EM and AM, respectively), and $14\,km \cdot h^{-1}$ (172 ± 6 $beats \cdot min^{-1}$ and 178 ± 6 $beats \cdot min^{-1}$ for EM and AM, respectively). The mean running velocity and heart rate that elicited a blood lac-

Table **2** Sprint running time for 5 m and 15 m, and velocity (V_3) and heart rate (HR_3) that elicited a blood lactate concentration of 3 $mmol \cdot l^{-1}$ during the endurance running test, in both groups

	Time in 5 m (s)	*Time in 15 m (s)*	*Velocity at 3 $mmol \cdot l^{-1}$ ($km \cdot h^{-1}$)*	*Heart rate at 3 $mmol \cdot l^{-1}$ ($beats \cdot min^{-1}$)*
Elite male players (n = 15)	1.03 (0.05)	2.46 (0.09)	11.8 (1)	156 (6.3)
Amateur male players (n = 15)	1.04 (0.03)	2.41 (0.07)	12.0 (1)	161 (9.3)

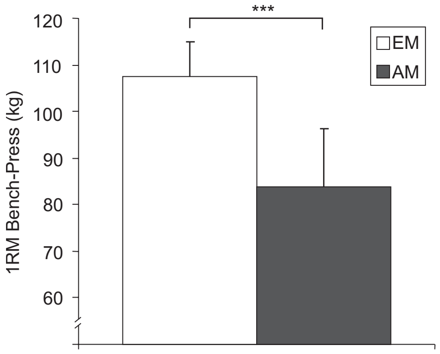

Fig. **1** One-repetition maximum (1 RM) bench-press in elite male team (EM) and amateur male team (AM). *** denotes significant difference ($p < 0.001$) between EM and AM teams. Values are means ± SD.

tate concentration of 3 $mmol \cdot l^{-1}$ were not different between groups (Table **2**).

Jumping test

The jumping height did not differ between EM and AM (46.8 ± 7 cm and 46.9 ± 7 cm for EM and AM, respectively).

Maximal strength and muscle power output

The maximal $1RM_{BP}$ values of 106.9 ± 11.6 kg in EM were 22% greater ($p < 0.001$) than those of 82.5 ± 14.8 kg recorded for AM (Fig. **1**). The shape of the average bench press power-load curves in absolute values differed between the groups (Fig. **2**). At all absolute loads examined (from 30% to 70% of 1 RM), average power output of the upper extremities was higher in EM ($p < 0.05 – 0.01$) than in AM. Average power output index at all loads in EM (451 ± 31.5 W) was 20% higher ($p < 0.05$) than in AM (359 ± 20.0 W).

The shape of the average concentric half-squat power-load curves in absolute values also differed between groups (Fig. **3 a**). At all absolute loads examined (from 60% to 125% of body mass), average power output of the lower extremities was higher in EM ($p < 0.05 – 0.01$) than in AM. Average power output index at all loads examined in EM (776 ± 97.2 W) was 16% higher ($p < 0.05$) than in AM (648 ± 97.2 W).

When muscle power output of the concentric half-squat actions was expressed relative to kilogram of body mass, the differences between the elite and the amateur team disappeared. Likewise, when muscle power output of the concentric half-squat actions was expressed relative to kilogram of free fatty mass (Fig. **3 b**), the differences between the elite and the amateur team disappeared. In the same way, when average power output index at all loads examined was expressed relative to kilogram of body weight (6.5 ± 0.2 $W \cdot kg^{-1}$ and 8.0 ± 0.3 $W \cdot kg^{-1}$ for EM and AM, respectively) or relative to kilogram of free fatty mass (9.5 ± 0.3 $W \cdot kg^{-1}$ and 9.1 ± 0.3 $W \cdot kg^{-1}$ for EM and AM, respectively), the differences between the elite and the amateur team disappeared.

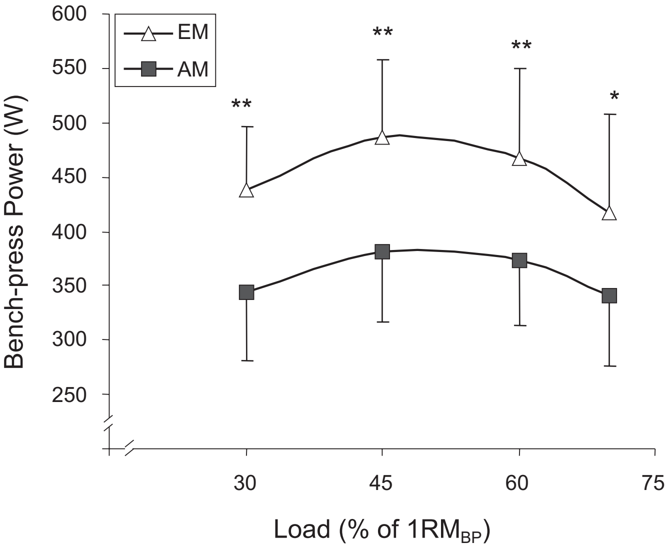

Fig. **2** Mean (± SD) muscle power output of the upper extremity muscles in the concentric bench-press action at different loads corresponding to the 30%, 45%, 60%, and 70% of individual maximal $1RM_{BP}$ in absolute value (* $p < 0.05$; ** $p < 0.01$).

Handball throwing velocity

The average handball velocity during the standing throw in EM (23.8 ± 1.9 $m \cdot s^{-1}$) was 8% greater ($p < 0.01$) than in AM (21.8 ± 1.6 $m \cdot s^{-1}$). As in the standing throw, the average velocity of handball throwing with 3-step running was 9% higher ($p < 0.01$) in EM (25.3 ± 2.2 $m \cdot s^{-1}$) than in AM (22.9 ± 1.4 $m \cdot s^{-1}$). In both teams, the average handball velocity with 3-step running throw was higher (5.9% and 4.8%; $p < 0.001$ for EM and AM, respectively) than in the standing throw.

Relationships between strength and throwing velocity

In both groups, the individual values in velocity at 30% of $1RM_{BP}$ correlated positively with the individual standing throw velocity values ($r = 0.67$ and 0.71; $p < 0.05 – 0.01$, for EM and AM, respectively).

In the EM, the individual 3-step running throw velocity values correlated significantly with the individual values of concentric

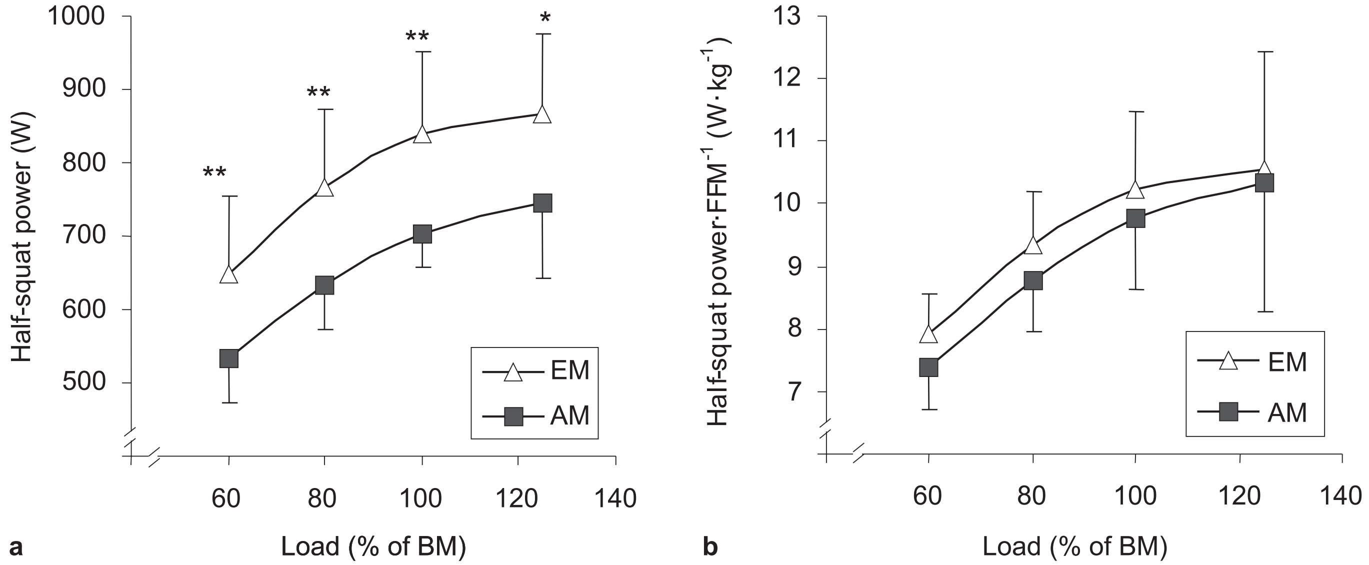

Fig. 3a and **b** Mean (± SD) muscle power output of the lower extremity muscles in the concentric half-squat action at different loads corresponding to the 60%, 80%, 100%, and 125% of individual body mass in absolute values (**a**), and normalized for free fatty mass (**b**) (* $p < 0.05$; ** $p < 0.01$).

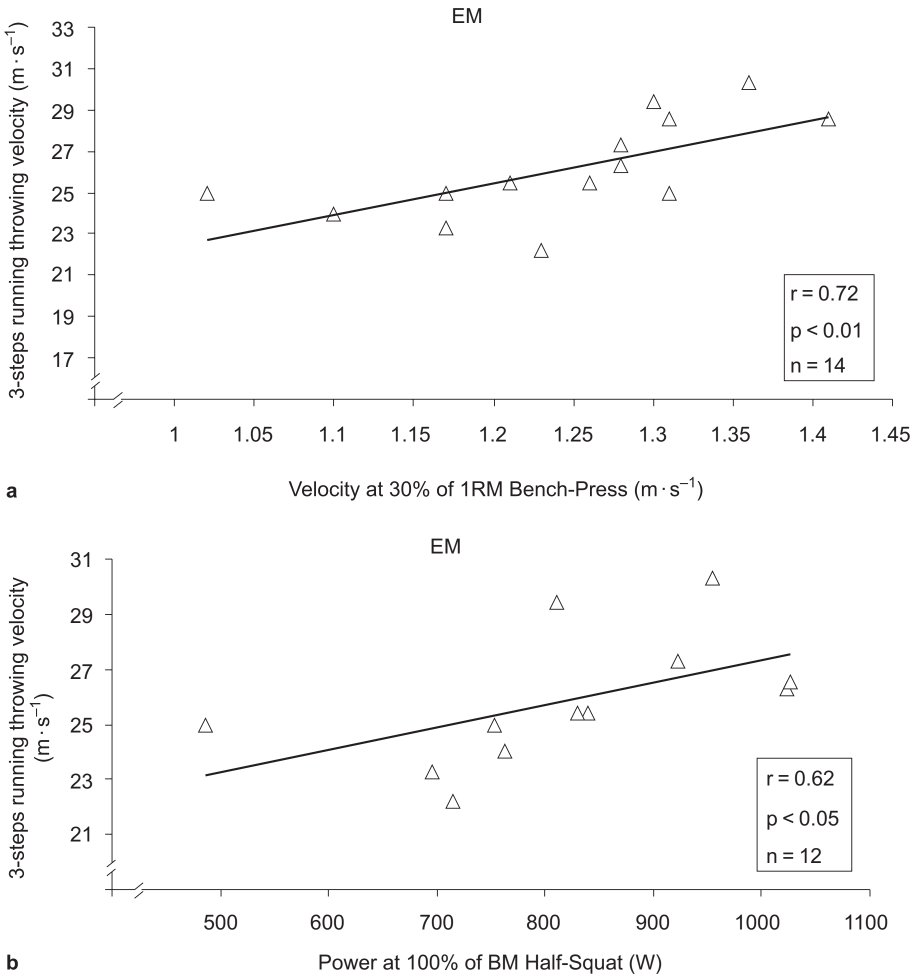

Fig. 4a and **b** The relationships between the individual values of 3-step running throw velocity and the individual values of concentric velocity production at load of 30% of $1RM_{BP}$ (**a**) as well as with the individuals' values of concentric power production at the load of 100% of body mass during half-squat action (**b**) in EM.

velocity production at the load of 30%, 60%, and 70% of $1RM_{BP}$ (from 0.57 to 0.72, $p < 0.05$) as well as with the individual values of concentric power production at the load of 60% and 100% of body mass (from 0.61 to 0.62, $p < 0.05$) during the half-squat action. In EM, the highest correlations observed with the 3-step running throw velocity were with the individual values of concentric velocity production at load of 30% of $1RM_{BP}$ ($r = 0.72$, $p < 0.01$) (Fig. **4a**), and with the individuals' values of concentric power production at the load of 100% of body mass during half-squat action ($r = 0.62$, $p < 0.05$) (Fig. **4b**). No significant correlations were found in AM between the individual values of 3-step running throw and maximal strength, power or velocity during bench press or during bilateral concentric half-squat actions.

Discussion

To our knowledge, this is the first study since the 1970s that simultaneously analyses anthropometric, jumping, running speed, throwing velocity, and endurance characteristics of a world-class male handball team (EM) compared to an amateur team (AM). In the present study, average body mass and free fatty mass in EM were 15% and 13% higher, respectively, than in AM, whereas no differences were observed in body height or percent body fat between the two teams. This shows that more powerfully built players are at an advantage in handball. For similar average body height (180 – 190 cm), the average body mass index (BMI; $kg \cdot m^{-2}$) in EM ($26.7\ kg \cdot m^{-2}$) was also higher than that reported in international elite national teams competing in the 70s and 80s ($23.7 – 25.5\ kg \cdot m^{-2}$) [4,9,12,16]. As this has been observed in other open-ended sports (shot put, throwing, football, rugby) [20], this suggests that elite handball players have been getting more corpulent over the last two decades. This increase in body mass has been related to number of factors including globalisation and international player recruitment, greater financial and social incentives, and advances in nutrition, ergogenic aids, training methods, or medical and kinesiological development techniques [20].

One of the major findings in the present study was that absolute maximal strength and power of the upper extremity muscles during bench-press and half-squat actions were 16 – 22% higher in EM than in AM. These strength and power differences between elite and lower level players have also been observed in other body contact sports such as rugby [2], and indicate that high absolute values of maximal strength and muscle power are required for successful performance in elite handball. When muscle power output during half squat at submaximal loads was expressed relative to kilogram of body mass, the differences observed between the handball groups in the ability to rapidly move different relative loads disappeared. Likewise, when muscle power output during half squat at submaximal loads was expressed relative to kilogram of free fatty mass, the differences observed between the handball groups in the ability to rapidly move different relative loads disappeared. This suggests that: 1) neural activation patterns and/or twitch tension per muscle mass under submaximal concentric half-squat actions are rather similar between EM and AM, and 2) the differences in free fatty mass alone could account for the differences observed between groups in absolute maximal strength and muscle power. However, the higher absolute levels of maximal strength and muscle power compared with AM, will give EM a clear advantage to sustain the forceful muscle contractions required during some handball game actions such as hitting, blocking, pushing, and holding.

No differences in vertical jump and sprint running performance were observed between EM and AM. Similar findings have been observed in other studies performed with international male handball players in the 70s and 80s [4,16]. This suggests that the mechanical power expressed relative to kilogram of body mass developed by elite handball players during jumping and sprint running is similar to that observed in lower level players and coincides with the similar muscle power output expressed per kilogram of body mass found in both groups during half-squat actions. However, the higher body mass of EM compared to AM allows them to produce higher absolute mechanical power during vertical jumping and sprint running. As pointed out for half-squat actions, this will give EM a clear advantage during some body-contact handball game actions.

It is difficult to compare the results of different studies that have measured throwing velocities in international level handball players because they differ markedly in a number of factors, including method of measurement (photoelectric cells, radar, cinematography), beginning of measurement (at the time of ball release or at 1 – 3-meter distance from the thrower) and type and direction of throwing. In any case, the mean velocity of standing throwing ($23.8 \pm 1.9\ m \cdot s^{-1}$) and 3-step running throwing ($25.3 \pm 2.2\ m \cdot s^{-1}$) measured in EM are the highest and the second highest, respectively, ever reported in the literature for international level handball players playing in the 70s and 80s (between $20 – 23.3\ m \cdot s^{-1}$ and between $21.9 – 28.1\ m \cdot s^{-1}$ for standing throw and 3-step running throw, respectively) [9,16, 18]. It may be speculated that one of the main characteristics of present world-class handball players compared to players in the 70s and 80s is higher ball throwing velocity. However, the interpretation of the above-mentioned observation must remain very cautious due to the marked differences observed between studies in methodological factors.

It was also interesting to observe that in EM and AM the individual values of velocity at 30% of $1RM_{BP}$ correlated significantly with individual values of ball velocity during standing throw. It indicates that those handball players with higher values of velocity at low relative loads during bench press actions may be able to throw the ball in a standing position at higher velocities vs. those with lower values, independently of handball level. It has been suggested that very fast low-load movements will selectively recruit and fire fast high-threshold motor unit [7,21]. In addition, Mikkelsen [16] found a significant correlation between relative surface of muscle type II fast fibres and standing throw velocity in international level handball players. These observations suggest that the faster handball throwers are able to better and/or more quickly activate fast muscles of the upper extremity during high-velocity low load-contractions.

In this study the correlation coefficients between power-load curves and the 3-step running throw were also examined. The results of the correlation analysis showed significant correlations in EM, but not in AM, between the individual values of velocity during 3-step running throw and the individual values of velocity at 30% of $1RM_{BP}$ as well as the individual values of power at 100% of body mass during half-squat actions. It indicates that the ball velocity of a world-class handball team in a 3-step running throw depends more on upper and lower extremity power output capabilities than in amateur handball players. The significant relationship observed between upper extremity high velocity movements and ball velocity during 3-step running throw in EM has been previously reported during concentric isokinetic elbow extensions in elite handball players [9]. This suggests that a fast 3-step running throw is related to the capacity to move low loads with upper body segments at maximal velocities [13]. This suggests that arm throwing velocity can be related to the capacity to quickly extend the limb at the hip and knee joints prior to trunk rotation and upper-extremity action [8,9,22].

The absence of relationships between muscle power output and a 3-step running throw in AM could be related to lower efficiency of arm throwing in AM compared with EM. Thus, arm throwing efficiency depends on muscle strength and power but also on throwing technique and on the capacity to coordinate complex fast sequential actions of body segments progressing from the larger leg and trunk actions to the faster moving actions of the more distal segments (shoulder, elbow, wrist, and finger) [13, 17]. It can be hypothesized that EM transfer energy to the ball during a 3-step running throw in a better-coordinated, efficient manner than AM. In this hypothesis, throwing velocity in AM should be more dependent on coordination and technique than on strength or muscle power characteristics. Further studies including kinematics analysis and sequential muscle timing activation need to be performed to clarify differences in handball throwing technique between players of different level.

Based on studies measuring heart rate and blood lactate levels during 30- to 60-min handball games, it has been estimated that handball level performance demands a high aerobic capacity [6, 15,16]. However, elite and lower level male handball players do not present high aerobic capacities because their average values of maximal oxygen consumption [1,6,10,16], percent of type I fibres [16], and succinate dehydrogenase activity in the vastus lateralis muscle [16] are 20 – 30% higher than in sedentary males, although similar to schoolchildren and much lower than long distance runners [16]. Moreover, player changes are particularly frequent in handball; during an official handball match they play an average of 25 – 30 minutes and only cover distances between 1.1 to 3.0 km [1,23], with a low average glycogen depletion in mixed muscle fibres (39% of the initial levels) [16], and low energy expenditure (from 500 to 800 Kcal [3]). This suggests that handball players do not need high aerobic capacities to excel in handball. Our results coincide with these studies because modest and similar average running velocity values (11.8 – 12.0 $\text{km} \cdot \text{h}^{-1}$) associated with a blood lactate concentration of 3 $\text{mmol} \cdot \text{l}^{-1}$, were found in EM and AM groups. From the present results it could therefore be suggested that endurance capacity does not represent a limitation for further performance in handball. However, this finding should be interpreted with caution since it is possible that a minimum level of endurance running must be reached to succeed in handball.

In conclusion, elite male handball players present similar values in body height, percent body fat, vertical jump height, sprint running time, and endurance running to AM, but present higher values in body mass, free fatty mass, 1RM_{BP}, average absolute muscle power output at all loads during bench-press and half-squat actions, as well as velocities at standing and 3-step running handball throw. The differences in free fatty mass alone could account for the differences in absolute maximal strength and muscle power observed between groups. However, the higher absolute levels of maximal strength and muscle power compared with AM will give EM a clear advantage to sustain the forceful muscle contractions required during some handball game actions. It is suggested that the higher throwing ball velocity of a world-class handball team depends more on upper and lower extremity power output capabilities than in amateur handball players.

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