

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

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Key words

- muscle strength
- muscle power
- endurance
- arm throwing
- women

Abstract

▼ This study compared physical characteristics (body height [BH], body mass [BM], body fat [BF], and fat free mass [FFM]), one repetition maximum bench press ($1RM_{BP}$), jumping explosive power (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 elite ($n = 16$; EF) and amateur ($n = 15$; AF) female handball players aged 17–38. Results revealed that, compared to AF, EF players presented similar values in body mass and percent body fat, but higher values ($p < 0.001–0.05$) in BH (6%), FFM (10%), $1RM_{BP}$ (23%), VJ (10%), handball throwing velocity

(11%), power-load relationship of the arm (25%) and leg (12%) extensors, as well as 5- and 15-m sprint (3–4%) and endurance running velocities (13%). Univariate regression analyses showed that $1RM_{BP}$ was associated with throwing velocity ($R^2 = 0.64$). The higher absolute values of maximal strength and muscle power, although explained by the differences in fat free mass, will give EF an advantage to sustain certain handball game actions. The association between $1RM_{BP}$ and throwing velocity suggests that throwing velocity values in female handball players depend more on maximal strength than on the capacity to move low loads at high velocities, during elbow extension actions.

Introduction

▼ Handball is a very strenuous body-contact team sport that places heavy emphasis on running, jumping, running speed and throwing [28], 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 are important for successful participation in elite levels of handball leagues. In a previous study in our laboratory comparing anthropometric and physiological characteristics between elite and amateur male handball players [11], elite players presented higher values in body mass, fat free mass, maximal dynamic strength during bench press actions, average absolute muscle power outputs at submaximal loads during bench press and half-squat actions as well as velocities at standing and 3-step running handball throw. In addition, ball-throwing velocity of elite male players depended more on upper and lower extremity power output capabilities than in amateur male handball players [11].

Only one study, in the 1970s, has compared certain anthropometric and nonspecific (i.e., Wingate test) physiological characteristics for elite female handball players of different ages (senior vs. junior) [18]. To our knowledge, no studies have compared current anthropometric, physiological and handball throwing characteristics for female handball players of different levels. Examination of fitness profile in female handball players can contribute to talent selection and identification and could be of great importance for the optimal construction of strength/power and endurance training programs to improve handball performance.

In female handball players, we hypothesized that differences between elite and amateur players regarding anthropometrics, strength, muscle power, handball throwing and sprint and endurance running characteristics will be similar to those found in males. Second, as found in males, 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 which fitness, anthropo-

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Table 1 Physical characteristics and training experience of elite female team (EF) and amateur female team (AF)

| | Age (years) | Height (cm) | Body mass (kg) | Body fat (%) | Free fatty mass (kg) | Training experience (years) |
|---------------------------------|----------------|------------------------|-------------------|-----------------|-------------------------|--------------------------------|
| Elite female players (n = 16) | 23.5 (4) | 175.4 (8) ^a | 69.8 (7) | 20.5 (5) | 55.1 (4) ^a | 12.7 (5) |
| Amateur female players (n = 15) | 21.4 (3) | 165.8 (4) | 64.6 (5) | 23.3 (3) | 49.7 (3) | 10.4 (3) |

^a Significant difference ($p < 0.05$) compared to amateur female handball players. Results are means (SD)

metric and specific throwing tests could differentiate between elite and amateur female 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.

Methods

Subjects

Two handball teams participated in the study. According to their competitive level, the subjects were divided into two groups: an elite female team (EF, $n = 16$; age: 23.1 ± 4 yr) and an amateur female team (AF, $n = 15$; age: 21.4 ± 3 yr). EF had similar handball training experience (11.7 ± 5 yr) to AF (10.2 ± 3 yr) and can be considered an elite handball team because: 1) they finished fourth in the Spanish handball champion last season, 2) seven of their players are (or have been) internationals and had won 15 Olympic and/or World Championship medals, and 3) the team qualified for the European Handball Cup (EHF) during the on-going season. AF players played in the National Second Division League and all of them were amateurs. Players underwent physical examination prior to commencing the study and each was cleared of any medical disorders that might limit their full participation in the study.

This study was carried out in October, 1 week after the end of the 7- to 8-week pre-competitive mesocycle. During the 7-week pre-competitive mesocycle, EF players had an average of 29 training sessions (4.1 training sessions per week) for a total average duration of 2946 minutes, distributed as follows: endurance training (15%), strength training (9%), speed training (1%) and playing sessions (50%). During the 7-week pre-competitive mesocycle, AF players had an average of 27 training sessions (3.9 training sessions per week) for a total average duration of 2510 minutes, distributed as follows: endurance training (23%), strength training (15%), and playing sessions (31%). During the whole pre-competitive mesocycle, four players from the EF group and two players from the AF group missed 2 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 in detail 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 design

A comparative study was conducted to determine if anthropometric and physical fitness parameters are different between female handball players of different competitive level. Two different groups of handball players were identified: elite and amateur females. 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. The test-retest intra-class 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 4.3%.

Testing schedule

The subjects were carefully familiarized with the testing protocol, as they had been previously tested 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. In the first session, each subject was subjected to a sprint and endurance running test. In the second session, each subject was tested for anthropometrical measurements and maximal and explosive strength and muscle power. In the third 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 fat free 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 ($\text{kg} \cdot \text{m}^{-2}$). Percentage of body fat was calculated from measurements of skinfold thickness [17]. Fat free mass (FFM, in kg) was calculated as the total body mass minus fat mass.

Sprint and endurance running test

After a non-standardized 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 on an indoor court, with a 90-s rest period between each sprint. During the 90-second 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 test-retest coefficient of variation for 5- and 15-m running times were 2.7% and 1.1%, respectively.

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 8.5 km·h⁻¹, 10 km·h⁻¹, 11.5 km·h⁻¹, and 13 km·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 preprogrammed 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 a hyperemic earlobe. Samples for whole blood lactate determination (100 µl) were deproteinized, stored at 4°C, and analyzed (YSI, 1500 Sport L-Lactate Analyzer, OH, USA). The blood lactate analyzer was calibrated after every fifth blood sample dose with three known controls (5, 15 and 30 mmol·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·l⁻¹ (V₃) 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 [32]. The test-retest coefficient of variation for V₃ was 2.2%.

Jumping test

The jumping test was performed on an indoor court and consisted of four maximal countermovement jumps with arms swinging on a contact platform (Newtest OY, Oulu, Finland). The subjects were asked to perform a maximal jump on the contact platform from a standing position, with a preparatory movement from the extend 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 a 10-s rest between jumps and a 90-s rest between sets. The best reading was used for further analysis. Absolute mechanical power during vertical jump (V_{Jp}) was calculated with the following formula:

$$V_{Jp} = BW \cdot g \cdot (2 \cdot g \cdot h)^{1/2}$$

in which "BW" is the body weight in kg, "g" the acceleration of gravity in m·s⁻², and "h" the jumping height in m. The test-retest coefficient of variation for jumping height was 2.4%.

Maximal strength and muscle power test

A detailed description of the maximal strength and muscle power testing procedure can be found elsewhere [16]. 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 [10]. 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 [16,25]. 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. The rest period between attempts was always 2 minutes. The test-retest coefficient of variation for 1RM_{BP} was 0.9%.

The power-load relationship of the arm extensor muscles was tested in the bench press exercise using the relative loads of 30%, 45%, 60% and 70% of 1RM_{BP} in EF and the relative loads of 45%, 60% and 70% of 1RM in AF. No test with relative loads of 30% of 1RM was performed in AF because the load corresponding to 30% of 1RM_{BP} was lower than the weight of the bar (i.e., 15 kg) in the majority of AF players. On command, the subject was instructed to perform, as fast as possible, the similar purely concentric action than the ride to end during the one repetition concentric maximum bench press testing (1RM_{BP}). Warm-up consisted of a set of 5 repetitions at loads of 30–45% of 1RM_{BP}. Two testing actions were recorded and the best reading (with the highest velocity) was taken for further analysis. The time period of rest between each trial and set was always 1.5 minutes. An averaged index of muscle power output with the loads from 45% to 70% of 1RM_{BP} was calculated in EF and AF. The power-load relationship of the leg extensor muscles was tested in the half-squat exercise, using the relative loads of 60%, 80% 100% and 125% of body mass (BM). In the half-squat position, shoulders were in contact with a bar and the starting knee angle was 90 degrees [16]. 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 loads of 40–60% of 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. An averaged index of muscle power output with the loads from 60% to 125% of body mass was calculated during half-squat actions in EF and AF. For comparison purposes, the ratio between absolute average power output index during bench press actions and the absolute average power output index during half-squat actions was calculated as follows:

$$\text{Ratio} = (\text{bench press average power output index} \times 100 / \text{half-squat average power output index})$$

During the lower and upper extremity test actions, bar displacement, average velocity (m·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

Table 2 Average blood lactate (BL) concentrations and heart rates (HR) during the endurance running test in the elite (EF) and amateur (AF) groups

| | 8.5 km·h ⁻¹ | | 10 km·h ⁻¹ | | 11.5 km·h ⁻¹ | |
|---------------------------------|----------------------------|-----------------------|----------------------------|-----------------------|----------------------------|-----------------------|
| | BL (mmol·l ⁻¹) | HR (bpm) | BL (mmol·l ⁻¹) | HR (bpm) | BL (mmol·l ⁻¹) | HR (bpm) |
| Elite female players (n = 16) | 1.5 (0.8) ^a | 145 (15) ^a | 2.1 (1.1) ^a | 160 (14) ^a | 3.9 (1.8) ^a | 172 (12) ^a |
| Amateur female players (n = 15) | 2.1 (0.6) | 162 (10) | 3.1 (0.9) | 176 (10) | 6.1 (1.6) | 186 (7) |

^a Significant difference ($p < 0.05$) compared to amateur female handball players. Results are means (\pm SD)

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 the 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. For comparison purposes, an averaged index of muscle power output with all absolute loads examined was calculated separately in EF and AF for half-squat and bench press actions. 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 [16]. The test-retest coefficient of variation for the power output values during bench press and half-squat actions were 3.2% and 4.3%, respectively.

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 standardized warming up, the subjects were instructed to throw a standard handball (mass 370 g, circumference 52 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- to 2-minute rest elapsed between sets of throws and 10–15 seconds elapsed between two throws of the same set. For motivation, players were immediately

informed of their performance. The throw with the highest average ball velocity was selected for further analysis. The test-retest coefficient of variation for handball throwing time was 1.8%.

Statistical procedures

Standard statistical methods were used for the calculation of the mean and standard deviations (SD). 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 experience of the handball players are presented in **Table 1**. The EF team showed higher fat free mass (10%, $p < 0.001$), and body height (6%, $p < 0.001$) than the AF team. There were no differences in body mass, percent body fat, body mass index (BMI, $\text{kg}\cdot\text{m}^{-2}$) and training experience between the teams.

Sprint and endurance running test

During the sprint running test, EF players exhibited 4% lower ($p < 0.05$) maximal sprint running time for 5 m than AF players (1.10 ± 0.05 s and 1.14 ± 0.03 s for EF and AF, respectively). Similarly, during the sprint running test, EF players exhibited 3% lower ($p < 0.05$) maximal sprint running time for 15 m than AF players (2.64 ± 0.09 s and 2.71 ± 0.08 s for EF and AF, respectively). The results of the endurance running tests are presented in **Table 2**. During the endurance running test, average blood lactate concentration was lower ($p < 0.05 - 0.01$) in EF than in AF at running velocities of 8.5 $\text{km}\cdot\text{h}^{-1}$, 10 $\text{km}\cdot\text{h}^{-1}$, and 11.5 $\text{km}\cdot\text{h}^{-1}$. Similarly, average heart rate values were lower ($p < 0.05 - 0.01$) in EF than in AF at running velocities of 8.5 $\text{km}\cdot\text{h}^{-1}$, 10 $\text{km}\cdot\text{h}^{-1}$ and 11.5 $\text{km}\cdot\text{h}^{-1}$. Mean running velocity that elicited a blood lactate concentration of 3 $\text{mmol}\cdot\text{l}^{-1}$ (V_3) was 13% higher ($p < 0.001$) in EF (11.1 ± 0.8 $\text{km}\cdot\text{h}^{-1}$) than in AF (9.7 ± 0.9 $\text{km}\cdot\text{h}^{-1}$).

Jumping test

No difference was observed in jumping height between EF and AF (34.9 ± 5 cm and 33.0 ± 3 cm for EF and AF, respectively). However, average absolute mechanical power produced during verti-

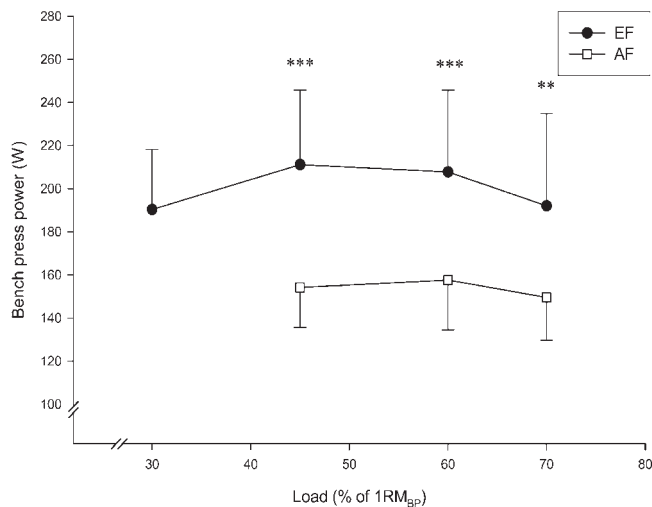


Fig. 1 Mean (\pm SD) muscle power output of the upper extremity muscles in the concentric bench press action at different loads corresponding to the 30% (only EF group), 45%, 60%, and 75% of individual 1RM_{BP} in absolute values (** $p < 0.01$; *** $p < 0.001$).

cal jump in EF (1787 ± 156 W) was 10% higher ($p < 0.01$) than in AF (1618 ± 143 W).

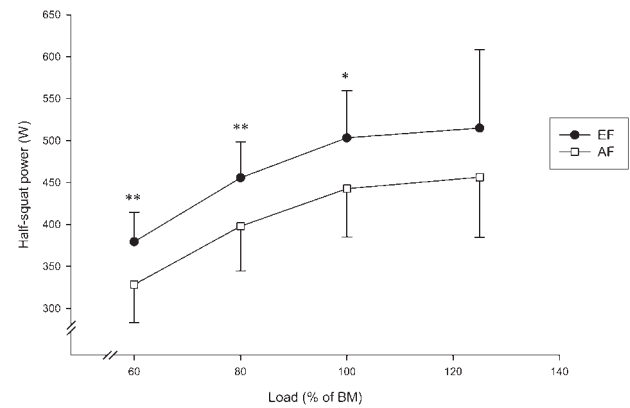
Maximal strength and muscle power output

The maximal 1RM_{BP} values of 47.9 ± 6.2 kg in EF were 23% greater ($p < 0.001$) than those of 36.7 ± 4.6 kg recorded for AF. The shape of the average bench press power-load curves in absolute values differed between the groups (● Fig. 1). At all absolute loads examined (from 45% to 70% of 1RM_{BP}), average power output of the upper extremities was higher in EF ($p < 0.05 - 0.001$) than in AF. Average power output index at loads examined (from 45 to 70%) in EF (203 ± 37.3 W) was 25% higher ($p < 0.001$) than in AF (153 ± 18.8 W). The shape of the average concentric half-squat power-load curves in absolute values also differed between groups (● Fig. 2A). At absolute loads examined (from 60% to 125% of body mass), average power output of the lower extremities was higher in EF ($p < 0.05 - 0.01$) than in AF. Average power output index at all loads examined (from 60% to 125% of body mass) in EF (463 ± 51.9 W) was 12% higher ($p < 0.01$) than in AF (406 ± 52.0 W). The ratio between absolute average power output index during bench press actions and absolute average power output index during half-squat actions (bench press average power output index \times 100/half-squat average power output index) was not different between groups ($43 \pm 9\%$ and $38 \pm 4\%$ for EF and AF, respectively).

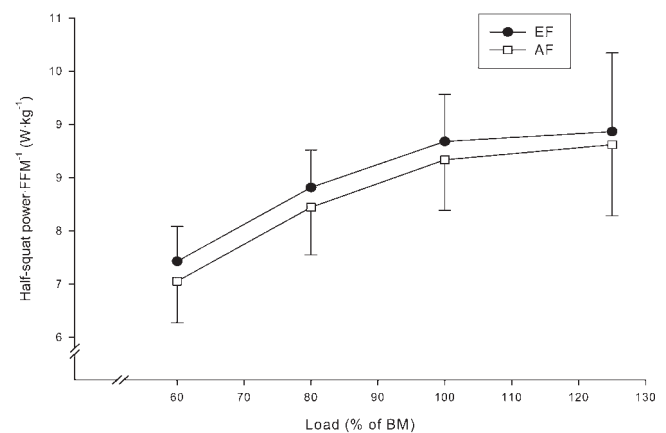
When muscle power output of the concentric half-squat actions was expressed relative to kilograms of body mass ($W \cdot kg^{-1}$), the differences between EF and AF were reduced from 12% to 9% ($p < 0.05 - 0.01$). When muscle power output was expressed relative to kilograms of fat free mass, the differences between the elite and the amateur groups disappeared (● Fig. 2B). Likewise, when average power output index at all loads examined was expressed relative to kilograms of fat free mass (8.4 ± 0.8 $W \cdot kg^{-1}$ and 8.2 ± 0.8 $W \cdot kg^{-1}$ for EF and AF, respectively), the differences between the elite and the amateur team disappeared.

Handball throwing velocity

The average handball velocity during the standing throw in EF (19.5 ± 1.1 $m \cdot s^{-1}$) was 11% greater ($p < 0.001$) than in AF



(A)



(B)

Fig. 2A and B Mean (\pm 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 fat free mass (B) (* $p < 0.05$; ** $p < 0.01$).

(17.4 ± 1.3 $m \cdot s^{-1}$). As in the standing throw, the average velocity of handball throwing with the 3-step running was 11% higher ($p < 0.001$) in EF (21.1 ± 1.3 $m \cdot s^{-1}$) than in AF (18.8 ± 1.2 $m \cdot s^{-1}$). In both teams, the average handball velocity with 3-step running throw was higher (8% and 7%; $p < 0.001$ for EF and AF, respectively) than in the standing throw.

Relationships between strength and throwing velocity

In both groups, the individual 1RM_{BP} values correlated positively with the individual standing throw velocity values ($r = 0.61$ and 0.69 , $p < 0.05$, $n = 16$ and $n = 11$ for EF and AF, respectively). The relationship between 1RM_{BP} values and the individual standing throw velocity values was greater when the group of female handball players was taken as a whole ($r = 0.80$, $p < 0.001$, $n = 27$) (● Fig. 3).

In the EF, the individual 3-step running throw velocity values correlated significantly with the individual values of concentric velocity production at the load of 30% of 1RM_{BP} ($r = 0.55$, $p < 0.05$, $n = 16$). In AF, the individual 3-step running throw velocity values correlated significantly with the individual maximal 1RM_{BP} values ($r = 0.81$, $p < 0.01$, $n = 11$), as well as with the individual values of concentric power production at the load of 80% of body mass related to fat free mass ($r = 0.67$, $p < 0.05$, $n = 10$) during the half-squat action.

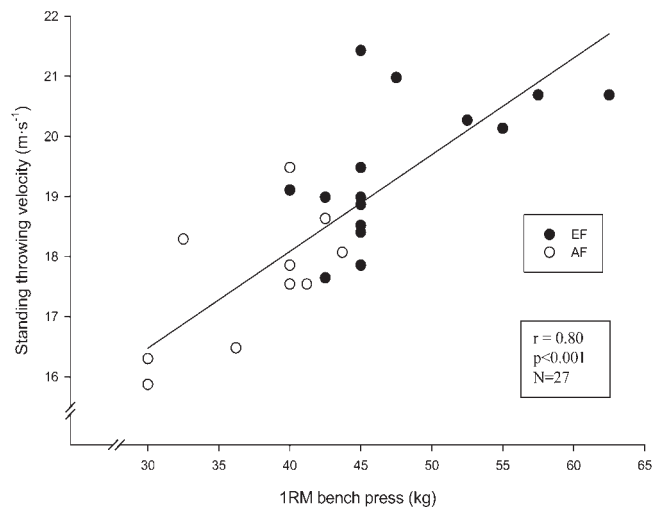


Fig. 3 The relationship between the individual values of one-repetition maximum bench press (1RM_{BP}) and the individual values of standing throw velocity for the female handball players as a whole.

Discussion

To our knowledge, this is the first study that simultaneously analyzes anthropometric, jumping, running speed, throwing velocity and endurance characteristics of a world-class female handball team (EF) compared to an amateur team (AF). In the present study, average height and fat free mass in EF were 6% and 10% higher, respectively, than in AF, whereas the differences observed in average body mass (7% higher in EF) or percent body fat (13% lower in EF) between the two teams were not statistically significant. As it has been shown in male handball players [11], in athletes specialized in throwing events [15], and in other open-ended sports (shot-put, throwing, football, rugby) [26], the present results suggest that taller and more powerfully built players are also at an advantage in female handball. The average body height (175 cm) of the present elite female players was similar to that reported in members of the Norwegian national female handball team in the '90s [19], but higher than that reported in the members of the Polish female handball team (170 cm) [18] in the '80s or in mixed groups of female players of different levels (playing in the first, second or third division) (169–171 cm) [14,20,29,30]. This increase in height has been related to a number of factors including international player recruitment, greater financial and social incentives, and advances in nutrition, ergogenic aids, training methods, or medical and kinesiological development techniques [26].

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 12–25% higher in EF than in AF. These strength and power differences between elite and lower level players have also been observed in male handball players [11]. This indicates that high absolute values of maximal strength and muscle power are also required for successful performance in elite female handball. When muscle power output during half-squat at submaximal loads was expressed relative to kilograms of body mass, the differences observed between the female handball groups in their ability to rapidly move different relative loads were reduced. Likewise, when muscle power output during half-squat at submaximal loads was expressed relative to kilograms of fat free mass, the

differences observed between the female handball groups in their ability to rapidly move different relative loads disappeared. This has also been observed in elite male handball players [11] and suggests that: 1) neural activation patterns and/or twitch tension per muscle mass under submaximal concentric half-squat actions are rather similar between EF and AF, and 2) differences in fat free mass alone could account for the differences observed between groups in absolute maximal strength and muscle power. However, the higher absolute and relative to kilogram of body mass levels of maximal strength and muscle power compared with AF will give EF a clear advantage as many of the handball skills such as hitting, blocking, pushing and holding require superior absolute strength and muscle power.

Compared to AF players, EF players were significantly faster over 5- and 15-m sprint running. This suggests that sprinting speed is an important characteristic of female handball. The higher sprint performance observed in EF over AF suggests that the mechanical power expressed relative to kilograms of body mass developed by elite female handball players during sprint running is higher to that observed in lower level female players and coincides with the higher muscle power output expressed per kilogram of body mass found in the elite group during half-squat actions. Although the average jumping height in EF was 5.5% higher than in AF, this difference was not statistically significant. This is an unexpected finding considering the higher muscle power output values observed in EF during half-squat actions when submaximal loads were expressed relative to kilograms of body mass. The intra-class test-retest reliability (CV: 2.4%) could partly explain the absence of differences observed between groups in vertical jumping heights values. However, the absolute mechanical power produced during vertical jump in EF was 10% higher than in AF. As pointed out for half-squat actions, the higher absolute mechanical power produced during vertical jumping and the higher sprint running performance will give EF a clear advantage during some handball game actions such as fast break, return to defence after a ball loss, jumping and one-on-one situations.

The average handball velocity during the standing throw and during 3-step running in EF was 11% higher than in AF. The higher fat free mass in EF compared to AF could largely explain the differences observed between both groups in handball throwing velocity [29]. However, differences in maximal strength and muscle power, coordination patterns, technique, and distribution of muscle fiber types could also explain, in part, these differences in throwing velocity between elite and amateur female handball players [3,29]. It is difficult to compare the results of the few studies that have measured throwing velocities in female 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 0–3-meter distance from the thrower), handball weight (between 350 and 370 g), handball level, and type and direction of throw. In any case, the mean velocity of standing throwing (19.5 and 17.4 m·s⁻¹ for EF and AF, respectively) measured in the present study are included in the range reported in the literature for female handball players playing in the first, second and third divisions of certain European countries [14,20,29,30]. However, interpretation of the above-mentioned observation must be made cautiously due to the marked differences observed between studies in methodological factors.

Table 3 Mean (SD) differences in some anthropometric, physical fitness and handball throwing velocity between elite female (EF) and elite male (EM) handball players. EM data from a previous study using elite male handball players published elsewhere [11]. Handball mass: females (370 g); males (480 g). Relative difference (%) = (EF-EM) × 100/EM; V_3 : velocity associated with a blood lactate concentration of 3 mmol·l⁻¹; W_{HS}/FFM (W): average power index from 60% to 125% during half-squat actions relative to fat free mass; $W_{indexBP}$ (W): average power index from 45% to 70% during bench press actions; $W_{indexHS}$ (W): average power index from 60% to 125% during half-squat actions; Ratio $W_{BP}/W_{HS} = W_{indexBP}$ (W) × 100/ $W_{indexBP}$ (W)

| Variable | EF | EM | Relative difference (%) |
|-------------------------------------|------------|---------------------------|-------------------------|
| Height (cm) | 175.4 (8) | 188.7 (8) ^a | - 7% |
| Body mass (kg) | 69.8 (7) | 95.2 (13) ^a | - 27% |
| Free fatty mass (kg) | 55.1 (4) | 81.7 (9) ^a | - 33% |
| V_3 (mmol·l ⁻¹) | 11.1 (0.8) | 11.8 (1) | - 6% |
| Time in 15 m (s) | 2.6 (0.1) | 2.5 (0.1) ^a | + 8% |
| Standing throw (m·s ⁻¹) | 19.5 (1.1) | 23.8 (1.9) ^a | - 18% |
| 3-step throw (m·s ⁻¹) | 21.1 (1.3) | 25.3 (2.2) ^a | - 17% |
| Vertical jump (cm) | 34.9 (5) | 46.8 (7) ^a | - 25% |
| 1RM _{BP} (kg) | 47.9 (6.2) | 106.9 (11.6) ^a | - 55% |
| W_{HS}/FFM (W) | 9.6 (1.1) | 8.5 (0.8) ^a | - 12% |
| $W_{indexBP}$ (W) | 203 (37) | 463 (35) | - 56% |
| $W_{indexHS}$ (W) | 463 (52) | 776 (97) | - 40% |
| Ratio W_{BP}/W_{HS} | 43 (9) | 59 (9) ^a | |

^a Significant difference ($p < 0.01 - 0.05$) compared to EF players

It has been suggested that in females, who in general possess rather low absolute strength levels, maximal strength may be important for explosive strength performance and development [12]. The results presented in **Fig. 3** support this suggestion because the individual values of 1RM_{BP} in EF and AF correlated significantly with individual values of ball velocity during standing throw. It indicates that those female handball players with higher values of maximal strength during bench press actions may be able to throw the ball in a standing position at higher velocities than those with lower values, independently of their handball level. This agrees with the results of Van den Tillaar and Ettema [29], showing that maximal specific isometric strength of the arm extensors was correlated with standing throwing velocity in female handball players playing in the Norwegian second and third divisions. Furthermore, some studies on elite and amateur female handball players have observed that upper extremity strength training leading to increases in maximal isometric [30] and dynamic [14] strength of the elbow extensors led to a significant increase in handball ball velocity during standing [14,30] and 3-step running [14] throws. Taken together, these findings strongly suggest that maximal strength of elbow extensors is an important factor in acquiring high ball velocities during overarm throwing in female handball players [30]. The association between standing throwing velocity and maximal strength during bench press actions observed in female handball players differs from the results obtained in male handball players, where the ability to throw the ball in a standing position was related with velocity at 30% of 1RM_{BP} but was not related to maximal strength [11]. This suggests that, as opposed to females, in male handball players, the level of performance at maximal strength may not be necessarily related to the capacity to throw the ball at high velocities.

The associations between power-load curves and the 3-step running throw were also examined in the present study. The results

of the correlation analysis showed significant relationships in AF, but not in EF, between the individual values of velocity during the 3-step running throw and the individual values of 1RM_{BP} as well as the individual values of power production at 80% of body mass related to fat free mass, during half-squat actions. The association observed between lower extremity muscle power and a 3-step running throw has also been found in elite male handball players and can be explained by the involvement of larger leg muscles during handball throwing [20]. In EF, no relationships were observed, however, between muscle power production of the lower extremity and a 3-step running throw. This absence of association in EF remains unclear because more efficient transfer energy from the larger leg and trunk actions to the faster moving actions of the more distal segments (shoulder, elbow, wrist and finger) should be expected to occur in elite compared to amateur handball players [11].

It has been shown that the running velocity associated with a given submaximal blood lactate concentration is an accurate predictor of aerobic capacity [7]. However, there is a paucity of information in female handball players about the blood lactate accumulation during a progressive running exercise. In the present study, average running velocity associated with a blood lactate concentration of 3 mmol·l⁻¹ (V_3) was modest (11.1 km·h⁻¹) in EF, but 13% higher than in AF. These results agree with previous studies measuring maximal aerobic power ($\dot{V}O_{2max}$), showing that: 1) $\dot{V}O_{2max}$ in female handball players is 20–30% higher than in sedentary young females, although substantially lower than in long distance female runners [4,9,19,27], and 2) average $\dot{V}O_{2max}$ values in elite female handball players (54 ml·kg⁻¹·min⁻¹) are around 10% higher than in amateur female handball players [14]. Taken together, these results suggest that, as has been observed in elite male handball players [2,8,11,13,22,23], female handball players do not need high aerobic capacities to excel in their sport. However, the differences observed in maximal oxygen consumption and in V_3 between elite and amateur female players suggest that aerobic capacity and maximal aerobic power can distinguish between female handball players of different standards and that a minimum level of endurance running must be reached to succeed in female handball.

The results of the present study and those of a recent study published elsewhere [11], performed in our laboratory with elite male handball players, allow for comparison between female and male elite handball players (**Table 3**). As expected, elite females presented lower average values than elite males in height (7%), body mass (27%), fat free mass (33%), endurance running (6%), sprint running velocity (8%), throwing velocity (17–18%), vertical jump (25%), maximal strength (55%) and average power output index (56%) during bench press actions, as well as average power output index during half-squat actions (40%). When muscle power output during half-squat actions at submaximal loads was expressed relative to kilograms of fat free mass, the gender differences observed in the ability to rapidly move different relative loads were reduced to 12%. This strengthens the notion that gender differences in muscle power in elite handball players are based mainly on difference in muscle bulk [29].

An interesting finding was that the ratio between the average power output index during bench press actions and half-squat actions was significantly lower ($p < 0.05$) in elite females than in elite males (43 ± 9% and 59 ± 9% for elite females and elite males, respectively). It indicates that, in elite handball players, the lower extremities muscle power output of females is significantly closer to that of males than their upper extremities

muscle power output is. Similar gender-differences between maximal strength [21,24] or muscle power (Wingate test) [31] capacities of the upper extremities compared to the lower extremities have also been reported earlier in sedentary or recreational subjects [24], and it has been suggested that these can be attributed, in part, to gender-differences in the pattern of daily physical use in normal life. The finding that similar gender-differences are observed in highly resistance-trained elite handball players suggests that they are not due to dissimilarity of use. Differences in hormonal, enzymatic and neurological factors, limb lengths, coordination patterns, muscle mass and the fact that women tend to have a lower proportion of their lean tissue distributed in the upper body could explain the greater gender-differences in upper body than in lower body strength [1,6,24,31]. Finally, the possibility that female athletes are less interested than males in developing their upper body for aesthetic reasons should not be ruled out.

In conclusion, elite female handball players present similar values of body mass and percent body fat to amateur female handball players, but higher values in body height, fat free mass, $1RM_{BP}$, average absolute muscle power output at all loads during bench press and half-squat actions, vertical jump power, sprint and endurance running performance, as well as ball throwing velocity. The differences in fat free mass could alone account for the differences in absolute muscle power observed between groups. However, the higher absolute levels of maximal strength, muscle power and running endurance compared with AF will give EF a clear advantage in sustaining forceful and frequent muscle contractions required during certain handball game actions. It is suggested that, due to their low absolute strength levels, ball throwing velocity of female handball players depends more on the level of performance at maximal strength than in the capacity to move low loads at high velocities during elbow extension actions. In view of the significant differences observed in anthropometric and physiological characteristics between both groups of female handball players, it is suggested that the battery of tests used in the present study is useful for assessing female handball. It remains to be elucidated if the observed physical fitness and throwing differences observed between elite and amateur handball players are due to genetic inherent differences and/or to level-differences in nutrition, ergogenic aids, training methods, and medical techniques.

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