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Title Page

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Performance factors in women's team handball. Physical and physiological aspects – A review

Running head: Performance factors in women's team handball.

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Performance factors in women's team handball. Physical and physiological aspects – A review.

Team handball is an Olympic sport played professionally in many European countries. Nevertheless, scientific knowledge regarding women's elite team handball demands is limited. Thus, the purpose of this article was to review a series of studies (n=33) on physical characteristics, physiological attributes, physical attributes, throwing velocity and on-court performances of women's team handball players. Such empirical and practical information is essential in order to design and implement successful short-term and long-term training programs for women's team handball players.

Our review revealed that (a) players that have a higher skill level are taller and have a higher fat-free mass; (b) players who are more aerobically resistant are at an advantage in international level women team-handball; (c) strength and power exercises should be emphasized in conditioning programs, as they are associated with both sprint performance and throwing velocity; (d) speed drills should also be implemented in conditioning programs but after a decrease in physical training volume; (e) a time-motion analysis is an effective method of quantifying the demands of team handball and provides a conceptual framework for the specific physical preparation of players.

According to our results, there are only few studies on on-court performance and time-motion analysis for women's team handball players, especially concerning acceleration profiles. More studies are needed to examine the effectiveness of different training programs of women's team handball players' physiological and physical attributes.

KEY WORDS: Anthropometric characteristics, sports performance, throwing velocity, on-court performance

INTRODUCTION

In this review, we use the term "handball" to refer to the game played between two teams, each comprising six court players and a goalkeeper (51).

Since its introduction in 1972 at the Summer Olympic Games (18), handball has become more popular as a sport in general. Handball is a very strenuous body-contact sport characterized by highly developed motor skills such as speed, explosive power, endurance, and strength (40). The athlete's performance in high-level women's handball depends directly on diverse physiological attributes. In order to reach maximum player performance in handball, it is essential to use knowledge from various sports-related domains, including exercise physiology and sports medicine (51).

Anthropometric characteristics such as body size, body mass, BMI, and body fat percentage, play a highly important role when discussing sport success and results (5, 43, 47). Ball throwing velocity is also an important factor in Handball (14, 15, 19). This velocity depends on the player's ability to accelerate the ball with an over arm throw, the duration of the movement, which reduces visual information for the goalkeeper, and the accuracy of the throw (6).

The importance of women's handball in reasearch literature has grown exponentially, with the most relevant articles published over the last five years (2, 13, 16, 17, 18, 20, 24, 26, 29, 40, 45, 46, 47, 48). We also have included some of our own unpublished data with a special focus on on-court movement characteristics. Nevertheless, evidence-based knowledge for trainers and sport scientists regarding women's elite team handball is limited, although necessary for further developing player's skills and handball in general. Therefore, the first objective of this review is to summarize the scientific knowledge in women's handball.

Information on training-related issues of women handball players, such as anthropometric measurements (e.g.16, 24), physiological attributes (e.g. 29, 30), physical attributes (e.g. 17, 21), throwing velocity and accuracy (e.g.16, 19, 44, 49), and on-court performance (e.g. 30, 33, 41), can be utilized effectively in women's handball programs, especially in strength and conditioning programs.

Thus, the current article has three aims: (a) to review a series of studies (n=33) on physical characteristics, physiological attributes, throwing velocity and accuracy, and on-court performances of women's handball players including: amateur players, professional players, and national team players; (b) to summarize the status of scientific knowledge in women handball including fields with a clear need for further studies in order to stimulate more research and (c) to suggest practical recommendations for women's handball coaches.

METHODS

A review of the literature on physical and physiological aspects of women handball players was conducted. The reviewed articles were selected from an extensive search of the literature in English, including major computerized databases (PubMed, Medline and SPORT Discus) and library archive search tools. Various combinations of keywords were used, including: handball, team, women's, women, physiological, physical and player. Data from unpublished studies conducted by the authors were also included. Ultimately, thirty three articles were included in this review.

RESULTS AND DISCUSSION

In order to plan, design and implement successful short-term and long-term training programs for women handball players, it is essential to gather information about the physical characteristics and physiological attributes of the players.

Physical characteristics

It is well known that body size affects physical performance. A taller person would perform better in activities with a significant strength component. Athletes specialized in throwing events are taller, heavier and more muscularly built than non-throwers. Body size has a strong positive effect on throwing performance and isometric strength (43, 47).

The number of studies dealing with anthropometric characteristics of women handball players is rather small in comparison to those for male athletes. A summary of the physical characteristics of women's handball players across the reviewed studies is presented in Table 1. The mean height of handball players ranged from 163 ± 7 cm in 181 adolescent Greek players (48) to 179.0 ± 0.0 cm in seven players of the Norwegian national team (39).

[INSERT TABLE 1]

The study recording the lowest mean body mass focused on young players (57.5 ± 7.9 kg) (43). In contrast, the studies that reported the highest mean body mass included the Norwegian national women's team (72.0 ± 6.3 kg (39); 71.6 ± 5.7 kg (21)). Body fat percentages ranged from 19.39 ± 4.5% in Croatian elite players (5) to 28.4 ± 3.6% for Norwegian national league players (43).

Michalsik (33) found that wing players were shorter and had less body mass than back and pivot players; and Cizmek et al. (5) found that wing players had the lowest height and weight, whereas goalkeepers were the tallest and the heaviest. These differences could be caused because of the specific requirements which dictate types and structures of movements performed by players. Wings players cover the biggest field area and perform most of the counterattacks; therefore they are in need of lighter, swift bodies with the ability of fast movement changes and agility (5). However, no significant differences in height and body mass were revealed according to the players' position (goalkeeper, back, centre and wing) for elite Asian women handball players (18) and elite players of the Spanish first division (46).

Granados et al. (17) assessed sixteen elite first league Spanish women players four times over the course of a season: during the first week after the beginning of the first preparatory period, at the beginning and the end of the first competition period, and at the end of the second competitive period. The researchers found no differences in body mass during the season, however fat-free mass significantly increased by 1.8 ± 1.2 % and per cent body fat significantly decreased by 9.0 ± 8.7 % ($p<0.01$) over the season.

Granados (16) and Milanese (34) compared elite (EP) and amateur (AP) women handball players. In both studies EPs were taller and had a higher fat-free mass than APs. The authors concluded that taller and more powerfully-built players have a competitive advantage in women's handball. Similarly, Bayios et al. (4) found that athletes at higher competition levels were taller, leaner and heavier and were more homogeneous in somatotype characteristics. These authors compared Greek women ball players (handball players, basketball players and volleyball players). Handball players were found to be the shortest with the highest values in body fat, being characterized by a great heterogeneity of their somatotype, which was mesomorph-endomorph (4.2-4.7-1.8). Volleyball players' somatotype was characterized as balanced endomorph (3.4-2.7-2.9) and basketball players' somatotype as mesomorph-endomorph (3.7-3.2-2.4). The same researchers found differences between elite and amateur handball players' somatotypes. While EPs were characterized as mesomorph-endomorph (4.0-4.1-1.8), APs were characterized as endomorph-mesomorph (4.3-5.2-1.8). Gholami et al. (13) found similar characteristics for Iranian national team handball players (mesomorph-endomorph; 3.6-4.7-1.7). A higher muscle mass is evidenced in the mesomorphic component in handball players constitutes a significant advantage in order to confront the intense body contact that takes place during a game.

In order to succeed in specific sport activities, it is often necessary to have certain physical characteristics. For ball games in which it is essential to use one's hands, hand morphology and functional properties may play a key role for performance (2). It is believed that a stable ball grip allows the athlete to accelerate the ball to a maximum during the entire throwing movement (42). According to two recently published studies, defined anthropometric characteristics such as hand and arm span seem to be the main factors which correlate to ball velocity (42, 47). An older study (22), however, did not find any correlation between ball velocity and segmental body lengths.

In conclusion, players with a higher skill level are taller and have a higher fat-free mass (4, 16, 34, 35, 43, 47). Players with larger hand can grab the ball more tightly and this fact probably gives the player the confidence to accelerate the ball as much as possible throughout the whole movement pathway (2, 42, 47). Maybe anthropometric characteristics ought to be taken into account in the talent identification when choosing a playing position.

Physiological attributes

Handball is a team sport of an intermittent nature which requires considerable physiological attributes such as the aerobic profile. A high aerobic capacity appears to be important in order to maintain a high level of performance over the 60 min of playing time.

Aerobic profile

Eleven studies examined the aerobic capacity of women's handball players. Seven of the studies mentioned collected maximal oxygen consumption (VO_{2max}) data of players from different competition levels, while the others focused on run velocities corresponding to certain blood lactate concentrations (Table 2).

[INSERT TABLE 2]

VO_{2max} of women's handball players from the Norwegian national team was 55.5 ± 3.9 ml·kg^{-1}·min^{-1} in one recent study (30) and 51.3 ± 2.3 ml·kg^{-1}·min^{-1} in an earlier research (21), both conducted on a treadmill. This would imply an 8 % increase in VO_{2max} data of a top-level team over a 10-year period. This increase in VO_{2max} was correlated with better performance of the Norwegian national team, as can be seen in the team's final placement during European or World Championships and the Olympic Games. The two lowest VO_{2max} values in national team handball players were 45.3 ± 5.5 ml·kg^{-1}·min^{-1} in Brazilian players (36) and 47.2 ± 4.5 ml·kg^{-1}·min^{-1} (28) in Spanish players. Vargas et al. (45) reported values of 45.3 ± 3.0 ml·kg^{-1}·min^{-1} in a study conducted on a cycle ergometer in Brazilian first league handball players. As noted by Ziv and Lidor (51) a cycle ergometer test may underestimate VO_{2max} values because handball players are not used to cycling and therefore local muscular fatigue may be responsible for general fatigue before the subject reaches his or her cardiovascular system limits. Jadach et al. (20) and Rohdal et al. (37) found intermediate values in players of the Polish national team (48.8 ± 3.4 ml·kg^{-1}·min^{-1}) and in a Norwegian amateur handball team (47.7 ± 4.1 ml·kg^{-1}·min^{-1}).

Four of the articles on aerobic performance in women's handball included values of run velocities corresponding to either 3 or 4 mmol/l^{-1} blood lactate (v_3 or v_4, respectively) determined in an incremental run test. Granados et al. (16) examined endurance capacity in a four-stage sub-maximal discontinuous progressive run test at velocities of 8.5, 10.0, 11.5 and 13.0 km/h^{-1} in women's elite and amateur players. The authors found lower blood lactate concentrations and lower mean heart rates in EPs as compared to APs during the first three run velocities. V_3 was 13% higher in EPs than in APs, indicating a higher aerobic performance of EPs. In addition, the same elite team was tested again when they reached an international level (5 years after the first study). V_3 increased by 7 % during these 5 years (15) indicating a higher need for aerobic performance in international level women's handball. These results for women's players differ from results for male players (14) in which no significant differences were found between the endurance capacity of elite and amateur players. Surprisingly these authors concluded that endurance is not an important performance factor in male handball.

After conducting a Mader test, Manchado et al. (29, 30) found v_4 values of 3.34 ± 0.31 m.s^{-1} and 3.65 ± 0.25 m.s^{-1} for the German national team and a German first league team, respectively, indicating that the German women national players at that time had a slightly lower aerobic performance compared to the players of the first league team.

In one study that simultaneously analyzed characteristics and physiological reactions in international women's team handball, Manchado et al. (30) found that individual endurance capacity determined individual demands and run performance during the matches. Players with a high level of VO_{2max} were able to run faster compared to players with a lower level of VO_{2max} with the same level of cardiac loads (no differences in heart rates). At the same time, players with a higher VO_{2max} mainly stayed in individual aerobic metabolic run intensity categories during the match. Furthermore, Manchado et al. (29) described a highly significant positive correlation between v_4 and the percentage of maximal heart rate used during the matches of the German national team at an international tournament. These two in-field studies clearly highlight the necessity of a highly developed basic endurance capacity to reduce cardiac demands and to likely optimize handball-specific performance during international matches.

Two further studies examined changes in aerobic capacity throughout the competition phase or the season in women's handball players. In the first study of sixteen players, Granados et al. (17) found no significant changes during the season in endurance capacity ($_{V3}$) measured four times during a 45-week season lasting from August to May. In the other study (21), handball players (n=8) slightly increased their VO_{2max} from 51.3 ± 2.3 to 53.8 ± 2.7 $ml.kg^{-1}.min^{-1}$ in the period when endurance training had priority and 2-3 weekly endurance training sessions were performed for six weeks.

In women's basketball players, Ziv and Lidor (50) described similar VO_{2max} values as those described in handball players (ranging from 44.0 to 54.0 $ml.kg^{-1}.min^{-1}$). In a study comparable to handball, Rodriguez-Alonso et al. (38) reported higher VO_{2max} values for basketball players participating at an international level as compared to those at a national level. In volleyball Lidor and Ziv (27) described VO_{2max} values ranging from 41.7 to 49.9 $ml.kg^{-1}/.min^{-1}$ which are slightly lower than the values reported for basketball and handball players, indicating a slightly lower importance of well-developed aerobic performance in this ball sport as compared to the other two sports.

Physical attributes

Modern style handball involves intense physical contact throughout the entire match in defense, counterattack and positional attack. Only players with high physical capacities can effectively satisfy such requirements (20). Thus, physical attributes such as power and strength, running speed, and throwing velocity are important factors for success in competitive women's handball. Therefore, these capacities are now discussed for women handball players.

Power and strength

Muscle strength is an important factor in handball performance (23). Most researchers agree that higher maximal power and strength may be associated with an advantage in blocking, hitting, pushing (16) and ball throwing velocity (3, 10, 22, 31). Nevertheless, little is known about changes in power and strength with regard to training in women's handball players. Only two studies that examined changes in power and strength with training were found. In one study, Granados et al. (17) found significant increases in one-repetition maximum (1RM) bench press from the beginning of the preparation phase (T_1) to the end of the first competition phase (T_3), with a 6.4 % increase of maximal values (from 45.8 ± 5.7 kg to 48.9 ± 6.5 kg). At the end of the second competitive period (T_4), the increase was 11.3 % (51.6 ± 6.7 kg) compared with

T_1. Moreover, muscle power output of the lower extremity was 7-13% higher at T_4 and T_3 compared with T_1 ($p<0.05$). In the other study, Jensen et al. (21) found maximal isometric strength increasing gradually from T_1 to T_3 (154.6 ± 25.7 N at T_1, 160.5 ± 24.8 N at T_2, and 168.9 ± 26.8 N at T_3, respectively). In contrast to the previous study (17), however, Jensen et al. (21) reported that maximal isometric strength tended to decrease again in T_4 compared to T_3. The authors concluded that increasing maximal isometric strength in women's handball players during a season is possible, even though many handball sessions are held in addition to specific strength training sessions.

Differences in power and strength have been shown to be relatively marked between elite and amateur players. Bench press 1RM was 23 % higher in EPs (47.9±6.2 kg) than APs (36.7±4.6 kg) (16). Power output of the upper extremities at all loads was also significantly higher in EPs. Similarly, average power output of the lower extremities at all loads examined was 12% higher in EPs than in APs. These findings suggest that high absolute values of maximal strength and muscle power are required for successful performance in elite women's handball. It was also found that when muscle power output during half-squat at sub-maximal loads was expressed relative to body mass kilograms, the differences observed between the two groups in their ability to rapidly move different relative loads were reduced, and disappeared when sub-maximal loads were expressed relative to kilograms of fat-free mass (16). This has also been observed in elite male handball players (14). In order to explain this fact the authors (16) suggest that 1) neural activation patterns and/or twitch tension per muscle mass under sub-maximal concentric half-squat actions are rather similar between EPs and APs, and 2) differences in fat-free mass alone could account for the differences observed in strength and muscle power. However, the maximal power and strength of EPs compared to APs will give them a clear advantage, as many of the handball skills such as hitting, blocking, pushing and holding require superior absolute strength and muscle power.

Running speed

Running speed is an important prerequisite factor in competitive handball (10). Sprint performances over 5 m and 15 m were reported by Granados et al. (16) to be different between elite and amateur women's handball players. EPs exhibited 4 % lower maximal sprint running time for 5 m than APs (1.10 ± 0.05 s and 1.14 ± 0.03 s for EPs and APs, respectively ($p<0.05$)). Similarly, EPs exhibited 3 % lower maximal sprint running time for 15 m than APs (2.64 ± 0.09 s and 2.71 ± 0.08 s for EPs and APs, respectively ($p<0.05$)). No changes in sprint performance were observed in elite women's players throughout the entire competitive season (17). According to the authors of the latter study, the progressive increase in training volume during the season, as well as the short time (less than 0.3 % of the total time) dedicated to sprint training, might explain the absence of changes observed in sprint running performance (17).

In contrast to the previous study, Jensen et al. (21) reported that maximal running velocity increased 2.2 % during the season in eight elite women's handball players. However, during the period with the heaviest strength training, the mean maximal running velocity tended to decrease, although 1-2 sprint training sessions were performed each week. According to the authors, this result may indicate that a decrease in physical training volume is important in order to increase sprint performance (21).

The power of the lower extremities and the maximum running speed are significantly correlated with ball throwing velocity (16, 31, 49). This is supported by the fact that the main factor affecting ball velocity is the effective energy transition from the ground to the lower extremities and through the kinematic chain to the throwing upper limb (3, 22). The correlation of running speed with ball throwing velocity indicates that as long as the ability of attaining maximum speed increases, the ball throwing velocity also increases (47). This correlation may be attributed to the percentage of fast-twitch muscle fibers (8) and neural aspects such as synchronization and recruitment of motor units (51). In high velocity movements like throwing, fast motor units are recruited preferentially (19).

Throwing velocity and accuracy

Throwing ability is one of the most vital skills in handball and a very important aspect for success (16). For a throw to be effective, the highest velocity at ball release in combination with aiming accuracy is required (19). The faster the ball is thrown at the goal, the less time the defenders and the goalkeeper have to save the shot.

A summary of studies examining throwing velocity and accuracy in women's handball players is presented in Table 3. These data should be interpreted with care, because there are very few studies, the methodologies used are different (radar gun, photogrammetry, photocell gates) and sample levels vary as well.

[INSERT TABLE 3]

Differences in throwing velocity between elite and amateur players were reported by Granados et al. (16). EPs threw the ball faster in the standing throw and the three-step running throw than APs (an 11 % difference, $p < 0.01$). In both groups, the average handball velocity with three-step running throw was higher (8 % and 7 %; $p < 0.01$ for EPs and APs respectively) than in the standing throw. In both groups, the individual one-repetition maximum bench press 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 EPs and APs, respectively). In the group of EPs, the individual three-step running throw velocity values correlated with the individual values of concentric velocity production at the load of 30 % of 1RM ($r = 0.55$, $p < 0.05$, $n = 16$). Furthermore, the individual three-step running throw velocity values correlated significantly with the individual maximal 1RM values in APs ($r = 0.81$, $p < 0.01$, $n = 11$).

The effectiveness of the throwing skill depends on both ball velocity and accuracy. Therefore, players should maintain their ability in both parameters throughout the game. However, the effort players exert during the game can potentially reduce the effectiveness in throwing skill over the course of the game, either in velocity or in accuracy (49). The influence of simulated game activities in throwing effectiveness (ball velocity and accuracy) in women's handball players was examined by Zapartidis et al. (47). Sixteen women handball players participated in simulated game activities which included distinctive handball activities for 60 min (2 halves of 30 min). For testing ball velocity and accuracy, subjects performed three shots on the spot towards a target from 7 m distance every 10 min. Throwing effectiveness was significantly affected by time, as aiming accuracy gradually decreased. However, ball velocity remained stable.

A number of studies have assessed the contribution of training to increasing throwing velocity in handball players. One study (17) examined changes in throwing velocity over a handball season in elite women's players and found significant increases in standing and three-step running throws at the end of the first preparatory period, the end of the first competitive period and at end of the second competitive period compared with the beginning of the season. In addition, significant correlations were observed from the beginning to the end of the season between throwing velocity changes and relative changes in physical performance.

A study examining the effects of maximum strength training on throwing velocity (19) found that after nine weeks of maximum progressive training using bench press and regular handball training, players had an increase of 18 % in the standing-throw velocity from pre-test to post-test and a 17 % increase in velocity in throwing with a 3-step run-in. However, control group players that participated only in regular handball training, also had an increase of 15 % in the standing-throw velocity from pre-test to post-test and a 9 % increase in velocity in throwing with a 3-step run-in, indicating that additional bench press training was not effective in increasing throwing velocity.

Van Muijen et al. (44) took an in-depth look at the effect of training with underweight and overweight balls on throwing performance. Players were trained during 8 weeks with a frequency of two sessions per week. They were randomly divided into three groups of fifteen subjects each: (1) a control group (CG) with regular training, using regular handballs (approximately 400 g), (2) a heavy training group (HTG) exercising with a heavy ball (approximately 500 g), and (3) a light training group (LTG) exercising with a light ball (approximately 300 g). In the two experimental groups, the players completed a specific throwing session of 30 maximal over-arm throws in addition to the regular training. After eight weeks of practice, there was a significant increase in ball velocity of 0.4 $m \cdot s^{-1}$ in LTG and no change in the CG and HTG, respectively. The authors concluded that the higher force for throwing needed by HTG reduced the velocity of the arm movement execution resulting in lower ball velocities.

On-court performances

Generally, it is interesting and useful for sport scientists and professional sport disciplines to learn more about the movements performed by players in sport games. Detailed information on the movements like, the distances covered by players, the velocities of their movements and position in two-dimensional space during a game provides comprehensive assessment of the demands of competition and assists in developing specific training regimes (7).

Continuous measurement of heart rates (HR) allows for an analysis of individual physiological demands during intermittent exercise, including team sports (32), because variations in HR during exercise correlate with a small time delay with alterations in exercise intensities (1). Only four studies examined HR during handball matches and among these studies, only one regarding women's top-level handball players during an official tournament (29). This study examined seven matches of the German women's national team (n = 14) during the European Championship in 2004 in Hungary. The study reported a mean HR of 85.8 % of maximum heart rate (HR_{max}) with a broad variation between players from 74.7 % to 91.7 %. Cardiopulmonary demands were very high for most of the players in all matches, showing wide periods close to individual HR_{max}. As indicated above, the authors demonstrated that the worse the individual basic endurance, the higher the individual loads during this highly demanding tournament. This clearly demonstrates the necessity of basic endurance training and the development of a high maximum oxygen uptake in international top-level handball. However, as no time-motion analysis was carried out during that study, no interrelations between movement patterns and physiological demands could be established.

In a more recent study, Manchado et al. (30) conducted time-motion analysis during matches of the German and Norwegian women's national teams. Eleven players from Germany and fourteen players from Norway at different positions (3 goalkeepers, 12 back, 10 wing and pivot) agreed to participate (age: 25.2 ± 2.8 years; height: 175.2 ± 6.3 cm; weight: 67.8 ± 4.9 kg.; VO_{2max}: 53.1 ± 4.8 $ml.kg^{-1}.min^{-1}$; HR_{max}: 194.8 ± 5.2 $b.min^{-1}$, v_4: 3.62 ± 0.25 $m.s^{-1}$). The study used the computerized SAGIT match analysis system. Mean HR during the match was approximately 86 % of HR_{max}, and for more than 90 % of playing time, it was higher than 85 % of HR_{max}. With the exception of the goalkeepers, who had lower values, no position-specific differences could be detected. During the second half of the match, players stayed in higher intensities with mean HR higher than 95 % of HR_{max} for a longer time period as compared to the first half of the match. Mean running distance during the match was 4614 m and varied widely between goalkeepers (2066 m) and field players (5251 m). Accordingly, mean running distance per minute also varied between goalkeepers (31.3 $m.min^{-1}$) and field players (69.7 $m.min^{-1}$). No significant differences could be detected between field players of different positions. Running distance per min was lower during the second half of the match (65.1 ± 18.0 $m.min^{-1}$) compared to the first half (71.5 ± 17.2 $m.min^{-1}$). The authors summarized that endurance capacity, being measured by means of VO_{2max} and v4, determines the individual demands during a handball match: players with a high level of VO_{2max} are able to execute activities with a higher intensity (measured as running distance per minute) as compared to players with a low level of VO_{2max}, with the same level of cardiac load (no differences could be detected in mean HR and % HR_{max}). At the same time, players with higher VO_{2max} mainly stay in aerobic metabolic intensity categories during the match.

In addition, horizontal sprint accelerations of the players were also analyzed during the same match (Manchado et al., submitted). Values for the different acceleration categories were: A1 < -4.5 $m.s^{-2}$; A2 ≥ -4.5 < -3 $m.s^{-2}$; A3 ≥ -3 < -1.5 $m.s^{-2}$; A4 ≥ -1.5 < 0 $m.s^{-2}$; A5 ≥ 0 < 1.5 $m.s^{-2}$; A6 ≥ 1.5 < 3 $m.s^{-2}$; A7 ≥ 3 < 4.5 $m.s^{-2}$; A8 ≥ 4.5 $m.s^{-2}$. One acceleration was counted whenever the player changed from one acceleration category to another. The authors found the total number of accelerations per minute to be high (nearly 200.min-1). Significant negative correlations were described between individual VO_{2max} values and the number of accelerations per minute in nearly all acceleration categories, including the total number of accelerations per minute. In contrast, significant positive correlations between VO_{2max} and the duration of the acceleration and the covered distance in all acceleration categories except for the highest and lowest categories (A1 and A8) were detected. In this study, the authors could demonstrate for the first time that acceleration profiles of horizontal movements in women's top level handball players depend on aerobic performance. The fitter the players were, the fewer number of acceleration actions they performed, but the longer they performed in all but the fastest of the different acceleration categories.

Michalsik (33) followed twenty four Danish women's elite handball players over a four-year period (2002-2006). A mean total distance of 4.0 km was covered per match with an average physical load corresponding to 79 % of VO_{2max} which has been calculated from heart rate measurements. A game consisted of up to 700 activity changes with an average of 27 high intense actions per match. In contrast to Manchado et al. (submitted) Michelsik (33) found distinct differences in the physical demands in the various playing positions, with wing players doing more high intensive work, covering a greater run distance, and tackling less compared to back players.

Another recent study compared the amount and variation of movements in kinematic and metabolic responses in seven elite handball players during training practice and official games at the end of the competitive period (41). Average HR during a game (165.0 ± 7.9 $b.min^{-1}$) was found to be similar with HR during training practice (164.6 ± 10.1 $b.min^{-1}$) corresponding to 90.1% and 89.9% of HR_{max}. However, time spent below 60 % HR_{max} was higher, and time spent above 81 % of HR_{max} was lower during practice as compared to games. Furthermore, players covered greater total distances and accounted for more high intensity running during games (5133 ± 243 m and 935 ± 152 m, respectively) compared to practices (3186 ± 426 m and 443 ± 95 m, respectively). During practice, the distance covered below the medium intensity running velocity was found to be higher and above this intensity found lower than games. The highest relative amount of time during practice (72.9 %) and during games (68.2 %) was spent standing and walking. The authors concluded that kinematic variables of training created lower metabolic demands compared to games.

Unfortunately, we could not identify any studies that directly measured oxygen consumption, blood lactate concentrations or other metabolic parameters during handball matches. This fact, in addition to the limited information on time-motion analyzes, prevents researchers and coaches from thoroughly quantifying the physiological demands imposed on handball players and conducting appropriate training regimes accordingly.

PRACTICAL APPLICATIONS

There are important practical applications from this study that can be applied to different areas of handball training:

- Physical characteristics: Body size, fat-free mass and percent of body fat seem to be important factors in physical performance, even within a rather homogeneous group of highly skilled athletes. Players with a higher skill level are taller and have a higher fat-free mass. Players with larger hand can grab the ball more tightly and this fact brings probably the player in a more confident situation to shoot the ball with higher velocity. The presence of higher muscle mass reflected in the mesomorphic component in women's handball players constitutes a significant advantage in order to confront the intense body contact during a game. Trainers should take into account some anthropometric data and particularly the hand size during handball talent selection because they tend to be a requirement for future high level performance.

- Endurance training: A high aerobic capacity appears to be important in order to maintain a high level of performance over the 60 min of playing time. Aerobic capacity and maximal aerobic power can distinguish between women handball players of different levels: more aerobically resistant players are at a clear advantage during international handball competitions. According to the reviewed studies, a highly developed basic endurance capacity seems to be important to reduce cardio-circulatory demands and to likely optimize handball-specific performance during the matches. However, training stimuli for high-intensity endurance training should be given more attention in the full training season planning instead of training at low intensity.
- Strength training: Strength and power exercises should be emphasized in conditioning routines in order to improve the percent of muscle mass and the required levels of maximal explosive strength of the upper and lower extremity muscles; because it should give the whole team an advantage to sustain the forceful muscle contractions required during some handball game actions, such

as blocking, hitting, pushing, jumping, sprint performance and throwing velocity. Those characteristics have been shown to differentiate players of different performance levels.

- Running speed: The relationship between running velocity, muscular power of the knee extensor muscle and throwing velocity emphasize the importance of increasing the time dedicated to sprint training and leg muscular strength but should be accompanied by a decrease in the total of the physical training volume and be specific to the actual demands of women team handball. Women handball coaches should design training periodization accordingly. The model where strength training had priority in the first part of the training period, followed by a period where sprint and endurance training had priority, seems to be able to increase both maximal oxygen uptake and maximal running velocity in women's handball players.

- Throwing velocity: 'Regular' handball training alone might lead to increases in throwing velocity over time. This specific throwing training might lead to even greater increases in combination with traditional resistance training. Resistance training induces improvements in muscle velocity and power during submaximal-load bench press and parallel squat actions. In addition, specific overloading throwing exercises using variably weighted handballs and/or core stability training routines should be performed.
- Time-motion analysis is an effective method of quantifying the demands of team handball and provides a conceptual framework for the specific physical preparation of players. An effective and efficient training regime should be based on a time-motion analysis and should include intermittent drills in which

handball players have to perform different motions with different paths/movements at the highest intensity possible, followed by lower intensity periods, all according to the specific demands of each playing position.

Future research needs

Besides the conclusions applicable to women's handball players training, we have drawn some future research needs:

- There is a need for more experimental studies. The most part of the reviewed studies were of descriptive nature and did not include intervention programs.
- There is a lack of research on the effectiveness of different types of aerobic training regimes for the improvement of aerobic performance in women's handball.
- There is a clear need for more research on strength training in women handball players. Studies focusing on the effects of different strength training regimes on handball specific performance factors such as running speed or throwing velocity, alone or in combination with endurance training programs are of particularly great importance.
- More studies are needed to quantify physiological loads on women handball players. These studies should use time-motion analyzes, focusing on specific handball actions such as jumping, running, walking or throwing in combination with on-court oxygen consumption and other metabolic parameter measurements during matches and training sessions.

REFERENCES

1. Achten, J., & Jeukendrup, A. E. Heart rate monitoring: Applications and limitations. *Sports Medicine,* 33(7), 517-538, 2003.

2. Barut, Ç., Demirel, P., & Kiram, S. Evaluation of hand anthropometric measurements and grip strength in basketball, volleyball and handball players. *Anatomy*, 2, 55-59, 2008.

3. Bayios, I. A., Anastasopoulou, E. M., Sioudris, D. S., & Boudolos, K. D. Relationship between isokinetic strength of the internal and external shoulder rotators and ball velocity in team handball. *Journal of Sports Medicine and Physical Fitness,* 41(2), 229, 2001.

4. Bayios, I. A., Bergeles, N. K., Apostolidis, N. G., Noutsos, K. S., & Koskolou, M. D. (2006). Anthropometric, body composition and somatotype differences of Greek elite women's basketball, volleyball and handball players. *Journal of Sports Medicine & Physical Fitness,* 46(2), 271-280, 2006.

5. Cizmek, A.; Ohnjec, K.; Vucetic, V. & Gruic, I. Morphological differences of elite Croatian women's handball players according to their game position. *Hrvat. Sportskomed. Vjesn,* 25: 122-127, 2010.

6. Debanne, T. & Laffaye, G. Predicting the throwing of the ball in handball with anthropometric variables and isotonic tests. *Journal of Sports Sciences,* 29(7), 705-713, 2011.

7. Duthie, G., Pyne, D., & Hooper, S. Time motion analysis of 2001 and 2002 Super 12 Rugby. *Journal of Sports Sciences, 23*(5), 523-530, 2005.

8. Faulkner, J. A., Claflin, D. R., & McCully, K. K. Power output of fast and slow fibers from human skeletal muscles. *Human Muscle Power,* 81–94, 1986.

9. Filaire, E., & Lac, G. Dehydroepiandrosterone (DHEA) rather than testosterone shows saliva androgen responses to exercise in elite women's handball players. *International Journal of Sports Medicine, 21*(1), 17-20, 2000.

10. Fleck, S. J., Smith, S. L., Craib, M. W., Denahan, T., Snow, R. E., & Mitchell, M. L. Upper extremity isokinetic torque and throwing velocity in team handball. *The Journal of Strength & Conditioning Research, 6*(2), 120, 1992.

11. Garcia, M.; Alcaraz, P.E.; Ferragut, C.; Manchado, C. ;Abraldes, A.; Rodriguez, N.; Vila, H. (2011). Body composition and throwing velocity in elite women's handball. *Ciencia, cultura y deporte,* 17 (7) vol 6, 129-135, 2011.

12. Garcin, M., Mille-Hamard, L., Devillers, S., Delattre, E., & Dufour, S. Influence of the type of training sport practised on psychological and physiological parameters during exhausting endurance exercises. *Perceptual and Motor Skills, 97*(3), 1150, 2003.

13. Gholami, M.; Sabbaghian Rad, L. Anthropometric, body composition and somatotype differences of Iranian elite women's basketball and handball players. *British Journal of Sports Medicine. 44 (14),* 119, 2010.

14. Gorostiaga, E. M., Granados, C., Ibanez, J., & Izquierdo, M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. *International Journal of Sports Medicine, 26*(3), 225-232, 2005.

15. Granados, C., Izquierdo, M., Ibañez, J., Ruesta, M., & Gorostiaga, E. M. Differences in physical fitness and performance over the years in an elite women's handball team. *Annual Congress of the European College of Sport Science,* Antalya. Turkey. ECSS Abstract Book p. 393, 2010.

16. Granados, C., Izquierdo, M., Ibanez, J., Bonnabau, H., & Gorostiaga, E. M. Differences in physical fitness and throwing velocity among elite and amateur women's handball players. *International Journal of Sports Medicine, 28*(10), 860-867, 2007.

17. Granados, C., Izquierdo, M., Ibàñez, J., Ruesta, M., & Gorostiaga, E. M. Effects of an entire season on physical fitness in elite women's handball players. *Medicine & Science in Sports & Exercise, 40*(2), 351-361, 2008.

18. Hasan, A. A., Reilly, T., Cable, N. T., & Ramadan, J. Anthropometric profiles of elite Asian women's handball players. *Journal of Sports Medicine & Physical Fitness, 47*(2), 197-202, 2007.

19. Hoff, J., & Almasbakk, B. The effects of maximum strength training on throwing velocity and muscle strength in women's team-handball players. *Journal of Strength & Conditioning Research, 9*(4), 255-258, 1995.

20. Jadach, A., & Ciepliński, J. Level of physical preparation and its influence on selection of game concepts for the Polish national handball women's team. *Polish Journal of Sport & Tourism, 15*(1), 17-22, 2008.

21. Jensen, J., Jacobsen, S. T., Hetland, P., & Tveit, P. Effect of combined endurance, strength and sprint training on maximal oxygen uptake, isometric strength and sprint performance in women's elite handball players during a season. *International Journal of Sports Medicine, 18*(5), 354-358, 1997.

22. Jöris, H. J. J., & Edwards, M. Force velocity and energy flow during the overarm throw in women's handball players. *Journal of Biomechanics, 18*, 409-414, 1985.

23. Kvorning, T. Strength training in team handball. Communication to the *5th International Conference on Strength Training*. Institut for Idraet og Biomekanif, Syddansk Universitet. October 2006.

24. Leyk, D., Gorges, W., Ridder, D., Wunderlich, M., Rüther, T., Sievert, A., et al. Hand-grip strength of young men, women and highly trained women's athletes. *European Journal of Applied Physiology, 99*(4), 415-421, 2007.

25. Lian, Ø. B., Engebretsen, L., & Bahr, R. Prevalence of jumper's knee among elite athletes from different sports. *The American Journal of Sports Medicine, 33*(4), 561, 2005.

26. Lidor, R., & Ziv, G. Physical and physiological attributes of women's handball players – a review. *Women in Sport and Physical Activity Journal, 20*(1), 23-38, 2011.

27. Lidor, R., & Ziv, G. Physical and physiological attributes of women's volleyball players-a review. *Journal of Strength and Conditioning Research, 24*(7), 1963-1973, 2010.

28. Manchado, C. *Datos de VO2máximo del equipo olímpico de balonmano femenino de España.* Unpublished data, 2004.

29. Manchado, C., Hoffmann, E., Navarro-Valdivielso, F., & Platen, P. Beanspruchungsprofil im Frauenhandball – Belastungsdauer und Herzfrequenzverhalten bei Spielen der Nationalmannschaft. *Deutsche Zeitschrift für Sportmedizin, 58*(10), 368-373, 2007.

30. Manchado, C., Navarro-Valdivielso, F., Pers, J., & Platen, P. Motion analysis and physiological demands in international women's team handball. Communication to the *Annual Congress of the European College of Sport Science*, Estoril, Portugal. ECSS Abstract Book p. 410, 2008.

31. Marques, M. C., & González-Badillo, J. J. In-season resistance training and detraining in professional team handball players. *Journal of Strength & Conditioning Research, 20*(3), 563-571, 2006.

32. McInnes, S. E., Carlson, J. S., Jones, C. J., & McKenna, M. J. The physiological load imposed on basketball players during competition. *Journal of Sports Sciences, 13*(5), 387-397, 1995.

33. Michalsik, L. Physical demands in modern women's elite team handball. Communication to the *Annual Congress of the European College of Sport Science*, Estoril, Portugal.. ECSS Abstract Book p. 494, 2008.

34. Milanese, C.; Piscitelli, F.; Lampis, C. & Zancanaro, C. Anthropometry and body composition of women's handball players according to competitive level or playing position. *Journal of Sports Sciences, 29*(12), 1301-1309, 2011.

35. Mohamed, H.; Vaeyens, R.; Matthys, S.; Multael, M.; Lefevre, J.; Lenoir, M. & Philippaerts, R. (2009). Anthropometric and performance measures for the development of a talent detection and identification model in youth handball. *Journal of Sports Sciences, 27*(3), 257-266, 2009.

36. Nogueira, T. N., Júnior, A. T. C., & Dantas, P. M. S. Perfil somatotípico, dermatoglífico e das qualidades físicas da seleção brasileira de handebol feminino adulto por posição de jogo. *Fitness & Performance Journal*, (4), 236, 2005.

37. Rodhal, S., Shalfawi, S., Enoksen, E., & Tonnessen, E. Physical fitness characteristics of Norwegian male and women's team handball players. Comunication at the *Annual Congress of the European College of Sport Science,* Antalya, Turkey. ECSS Abstract Book p. 497, 2010.

38. Rodriguez-Alonso, M., Fernandez-Garcia, B., Perez-Landaluce, J., & Terrados, N. Blood lactate and heart rate during national and international women's basketball. *The Journal of Sports Medicine and Physical Fitness, 43*(4), 432, 2003.

39. Ronglan, L. T., Raastad, T., & Børgesen, A. Neuromuscular fatigue and recovery in elite women's handball players. *Scandinavian Journal of Medicine & Science in Sports*, *16*(4), 267-273, 2006.

40. Saeterbakken, A. H., van den Tillaar, R., & Seiler, S. Effect of core stability training on throwing velocity in women's handball players. *The Journal of Strength & Conditioning Research, 25*(3), 712, 2011.

41. Sahin, Z., Hazir, T., Asci, A., & Acikada, C. Time-motion analysis and physiological responses of women's handball players during practices and official games. *Annual Congress of the European College of Sport Science*, Antalya, Turkey. ECSS Abstract Book p. 502, 2010.

42. Skoufas, D., Skoufa, E., Christodoulidis, T., Papadopoulou, S., Patikas, D., & Zaggelidis, G. The effect of arm and forearm loading on the throwing velocity of novice handball players: Influences during training and detraining. *Physical Training Nov 2008, 19*, 811-821, 2008.

43. Van der Tillaar, R., & Ettema, G. Effect of body size and gender in overarm throwing performance. *European Journal of Applied Physiology, 91*(4), 413-418, 2004.

44. Van Muijen, A. E., Joris, H., Kemper, H. C. G., & Van, I. S. Throwing practice with different ball weights: Effects on throwing velocity and muscle strength in women's handball players. *Sports Medicine, Training & Rehabilitation, 2*(2), 103-113, 1991.

45. Vargas, R. P., Dick, D. D., de Santi, H., Duarte, M., & da, C. J. Evaluation of physiological characteristics of women's handball athletes. *Fitness & Performance Journal (Online Edition), 7*(2), 93-98, 2008.

46. Vila, H.; Manchado, C.; Rodriguez, N.; Abraldes, A.;Alcaraz, P.; Ferragut, C. Anthropometric profile, vertical jump and throwing velocity, in women's elite handball players by playing positions. *The Journal of Strength & Conditioning Research*, 26(8),2146-2155, 2012

47. Zapartidis, I., Skoufas, D., Vareltzis, I., Christodoulidis, T., Toganidis, T., & Kororos, P. Factors influencing ball throwing velocity in young women's handball players. *Open Sports Medicine Journal, 3*, 39-43, 2009a

48. Zapartidis, I., Toganidis, T., Vareltzis, I., Christodoulidis, T., Kororos, P., & Skoufas, D. Profile of young women's handball players by playing position. *Serbian Journal of Sports Sciences, 3*(1-4), 53-60, 2009b

49. Zapartidis, I., Gouvali, M., Bayios, I., & Boudolos, K. Throwing effectiveness and rotational strength of the shoulder in team handball. *Journal of Sports Medicine and Physical Fitness*, *47*(2), 169, 2007.

50. Ziv, G., & Lidor, R. Physical attributes, physiological characteristics, on-court performances and nutritional strategies of women's and male basketball players. *Sports Medicine, 39*(7), 547, 2009a

51. Ziv, G., & Lidor, R. Physical characteristics, physiological attributes, and on-court performances of handball players: A review. *European Journal of Sport Science, 9*(6), 375-386, 2009b.

TABLES

Table 1. Summary of studies on physical characteristics of women's team-handball players

Table 2. Summary of studies on the aerobic profile of women's team-handball players; data are given as mean ± standard deviation

Table 3. Summary of cross sectional and training intervention studies on throwing velocity and throwing accuracy in women's team-handball players; data are given as mean ± standard deviation

Table 1. A summary of studies on physical characteristics of female team-handball players

Study	n	Play position/ participants	Age (years)	Training (years)	Height (cm)	Body mass (kg)	BMI	Percent fat (%)	Fat-free mass (kg)
Bayios&Bergeles (4)	101	Greek first NL	21.5 ± 4.6	8.8 ± 4.2	165.9 ± 6.3	62.1 ± 9.1	23.6 ± 2.7	25.9±3.3	48±6
	121	Greek second NL							
Cizmek et al (5)	37	Elite Croatian P.	24.49±4.14		174.74±6.75	69.46±8.57	22.70±1.99	19.39±4.50	
Filaire & Lac (9)	14	French National level	24.1 ± 2.6		167.8 ± 5.3	61.0 ± 7.5			
Granados et al.(16)	16	Elite Spanish P.	23.8 ± 4	12.7 ± 5	175.4 ± 8	69.8 ± 7	20.5 ± 5		
	15	Amateur players	21.4 ± 3	10.4 ± 3	165.8 ± 4	64.6 ± 5	23.3 ± 3		
García et al (11)	11	Spain NT	28.07±4.41		174.10±6.01	68.55±7.88	22.58±1.9		
	16	Spain B NT	22.09±3.33		176.55±7.93	71.13±7.77	23.45±1.9		
	14	Spain Junior NT	18.42±0.62		169.93±4.51	69.26±9.62	23.95±2.9		
	18	Spain Young NT	16.74±0.59		168.67±16.50	70.36±12.13	25.73±9.7		
Garcin et al. (12)	11	French League	19 ± 0.8		168.4 ± 2.5	62.0 ± 5.2			
Hasan et al. (18)	11	Goalkeeper/Asian NT	23 ± 2.1		175.8 ± 0.01	68.3 ± 6.3	23.3 ± 2.8	23.3±2.8	
	24	Back / Asian NT	22 ± 1.4		169.3 ± 0.02	62.2 ± 2.1	19.4 ± 2.4	19.4±2.4	
	13	Center/Asian NT	23 ± 4		171.8 ± 0.04	66.9 ± 4.5	20.6 ± 3		
	12	Wings/ Asian N.T	21± 2		170.0 ± 0.08	63.5 ± 7.9	21.8 ± 2.9	21.8±2.9	
Jadach et al. (20)	15	Poland NT	26.4		173.3	68.3	22.1		
Jensen et al., (21)	8	Norway NT	20.4±2.3		174.3±6.7	71.6±5.7			
Leyk et al., (24)	15	Elite Germany	22.6±4.7		172.0±0.5	68.7±4.8	23.3±2.3	25.6±5.5	51.0±2.7
Lian, et al. (25)	52	Norway NT	22.8 ± 4.3	14.9±4.2	172 ± 6	68.8 ± 8.4			
Manchado et al.(29)	16	Germany NT	26.6±3.8		176.0±7.4	70.4±6.8			
Michalsik (33)	24	Wings/Denmark NL	25.7±3.3		169.3	63.5			
		Pivot/Denmark NL			177.7	72.5			
		Back/Denmark NL			177.0	70.6			
Milanese et al. (34)	26	Elite Italian P.	26.4±5.77		169.2±6.04	67.0±7.91	23.4±5.33	23.3±5.33	
	17	Amateur Italian P.	17.3±2.25		166.0±5.10	64.4±10.47	23.3±4.01	28.6±4.01	
Ronglan et al. (39)	7	National Norway	23.7 ± 2.1		179.0 ± 0.04	72.0 ± 6.3			
	8	Norway NT	23.1 ± 2.0		176.0 ± 0.05	71.2 ± 1.8			
Saeterbakken et al. (40)	24	Young Norway	16.6±3.1	8.1±1.4	1.69±7.3	63.0±5.9			
Van den Tillaar&Ettema (43)	20	Norway NL	22.2 ±2.6	13.2±2.7	170.9±6.2	69.0±8.7		28.4±3.6	
Vargas et al. (45)	20	National Brazil	18,0±2,1		170.23±6,21	64.9±7.1			
Vila et al. (46)	130	Elite Spainish P.	25.74 ± 4.84	14.92 ± 4.88	171.31 ± 7.42	67.55 ± 8.06	22.97 ± 1.86		
Zapartadis et al.(48)	181	Young Greece	14.12±1.09	3.41±1.67	163±7.0	57.46±7.94	21.49±2.35		
Zapartidis et al.(49)	16	Greek first NL	20.5±1.9	8.5±1.8	168±0.08	62.38±6.19			

NT.:National Team NL: National League P: Players TBP: to be published

Table 2. A summary of studies on aerobic profile of female team-handball players

Study	**Participants**	**Method**	**Age (years)**	**Height (cm)**	**Body mass (kg)**	**VO_{2max}** ***ml/kg/min***	**V_4 V_3 (m/s)**	**FC** ***p/m***
Granados et al. (16, 17)	Amateur N= 15 Spain	Submaximal Progressive running test	21.4±3	165.8±4	64.6±5		2.5±0.3 (V3)	
	Elite N=16		23.1±4	175.4±8	69.8±7		3.06±0.2 (V3)	
Granados et al. (15)	Spain Elite Team N=14	Submaximal Progressive running test	27.0±3	175.7	70.3		3.24 (V3)	
Jadach (20)	Poland National Team	Treadmill	26.4	173.3	68.3	48.75±3.38		190.0±7.8 HRmax
Jensen et al., (21)	Norway National Team N=8	Treadmill				51.3 ± 2.3		
Manchado (28)	Spain National Team N=16	Treadmill				47.2 ± 4.5		
Manchado *et al*.(29)	Germany National Team N=14	Mader test (V_4) HR during matches	26.6±3.8	176.0±7.4	70.4±6.8		3.34±0,31 (V_4)	161,1± 3.3 HRwork 86% HRmáx
Manchado, et al.(30)	Norway National Team N=14	Treadmill	25.9 ± 2.2	175.9 ± 6.4	67.5 ± 6.4	55.5 ± 3.9	3.73±0.19 (V_4)	194.9 ± 4.3 HRmax
Manchado, et al.(30)	Germany 1st Division	Treadmill	24.5 ± 3.4	174.4 ± 6.5	68.2 ± 3.5	50.2 ± 4.3	3.47±0,23 (V_4)	194.8 ± 6.3 HRmax
Michalsik (33)	Denmark Elite players N=24	Treadmill	27.7±3.3	174.9±5.7	70.3±7.4	47.5		
Nogueira et al. (36)	Brazil National Team N=17	Treadmill	25.6±3.7	173.6±5.4	66.4±7.7	45.3±5.4		
Rodahl et al. (37)	Norway National League	Treadmill	22.1 ± 4.5	172.0± 6.4	68.2± 7.4	47.7 ± 4.1		
Vargas et al.(45)	Brazil 1st Division	Cicle ergometer	18,0±2,1	170,23±6,21	64,9±7,1	45,3±3,0		

Table 3. A summary of studies on throwing velocity and accuracy in female team-handball players

<table>
<tr><th>Study</th><th>Participants and methodology</th><th>Treatment</th><th>Characteristics of throw Velocity (m.s^{-1})</th></tr>
<tr><td>Granados et al. (16)</td><td>Elite players (n=16)
First Spanish League
Amateur players (n=15)
Photocell gates</td><td>Descriptive study</td><td>Standing throw: Elite players: 19.5±1.1 Amateur players: 17.4±1.3
Three steps throw: Elite players: 21.1±1.3 Amateur players: 18.8±1.2
11% difference between elite and amateur players
8-7% difference between standing and three steps throw, respectively.</td></tr>
<tr><td>Granados et al. (17)</td><td>Elite players (n=16)
First Spanish league
Photocell gates</td><td>Follow-up during a season.
Testing at beginning of the preparation phase (T1), beginning and end of first competition phase (T2 and T3, respectively), and end of second competition phase (T4)</td><td>Standing throw: T1: 19.0±0.9, T2: 19.5±1.2, T3: 20.2±1.7, T4: 20.5±1.3
Three steps throw: T1: 20.0±1.3, T2: 21.1±1.3, T3: 21.5±1.4, T4: 21.8±1.4
Significant increases (p<0.01) for both types of throwing at T4, T3 and T2 compared with T1</td></tr>
<tr><td>Hoff and Almasbakk, (19)</td><td>Norway 2nd Division (n=16)
Aged 17 to 26 years
Photogrametry</td><td>9 weeks of training, 3 sessions per week
Group 1: Maximum strength bench-press training + normal handball training
Group 2: Only normal handball training</td><td>Standing throw:
Group 1: pre: 19.8±2.34, post: 23.3±1.79, improvement: 3.5±0.88 (18%)
Group 2: pre: 18.5±1.29, post: 21.1±0.97, improvement: 2.7±1.64 (15%)
Three steps throw:
Group 1: pre: 23.1±2.01, post: 27.0±2.33, improvement: 3.9±1.12 (17%)
Group 2: pre: 22.6±1.78, post: 24.6±1.47, improvement: 2.0±1.53(9%)</td></tr>
<tr><td>Van Muijen et al., (44)</td><td>1-2 National Level (n=45)</td><td>8 weeks of training (60 throws per week)
Control group (CG): normal handball training
Heavy training group (HT): 500 gr. balls
Light training group (LT): 300 gr. balls</td><td>Standing throw:
No changes in CG and HT groups.
LT group: pre: 16.90±1.28, post 17.26±1.27, improvement: 2%</td></tr>
<tr><td>Vila et al., (46)</td><td>Elite players (n=130)
First Spanish league
Radar gun</td><td>Descriptive study. Four types of throws tested:
7m
9m standing just behind the line
9m with three step running
9m with an upward jump</td><td><table>
<tr><th>Position</th><th>n</th><th>7m</th><th>9m standing</th><th>9m three steps</th><th>9m jump</th></tr>
<tr><td>Center</td><td>16</td><td>20.80±1.42</td><td>21.11±1.48</td><td>23.11±1.10</td><td>22.47±1.59</td></tr>
<tr><td>Back</td><td>36</td><td>20.93±1.68</td><td>21.05±1.57</td><td>22.96±1.88</td><td>22.33±1.59</td></tr>
<tr><td>Wing</td><td>41</td><td>20.30±1.64</td><td>20.45±1.55</td><td>22.10±1.7</td><td>21.78±1.42</td></tr>
<tr><td>Pivot</td><td>18</td><td>21.02±1.84</td><td>20.78±1.87</td><td>22.53±1.77</td><td>22.00±2.00</td></tr>
<tr><td>Goalkeeper</td><td>19</td><td>19.52±0.93</td><td>20.23±1.02</td><td>21.75±1.68</td><td>20.79±1.72</td></tr>
<tr><td>Total</td><td>130</td><td>20.58±1.63</td><td>20.74±1.55</td><td>22.52±1.74</td><td>21.98±1.62</td></tr>
</table></td></tr>
<tr><td>Zapartidis et al. (49)</td><td>Greece 1st Division (n=16)
Age: 20.5 ± 1.9
Radar Gun</td><td>Descriptive study.
Simulated game activities for 60 min (2 halves of 30 min). Ball velocity and accuracy tested every 10 min.
3 shots on the spot from 7 m distance.</td><td><table>
<tr><th>Measurement</th><th>Ball velocity (m.s^{-1})</th><th>Accuracy (cm)</th></tr>
<tr><td>A1</td><td>16.52±1.64</td><td>28.27±7.79</td></tr>
<tr><td>A2</td><td>16.92±1.52</td><td>27.55±7.73</td></tr>
<tr><td>A3</td><td>16.56±1.64</td><td>31.64±8.66</td></tr>
<tr><td>B1</td><td>16.64±1.41</td><td>29.18±7.06</td></tr>
<tr><td>B2</td><td>16.81±1.57</td><td>29.6±9.22</td></tr>
<tr><td>B3</td><td>16.6±1.59</td><td>33.14±7.33</td></tr>
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