

Research article

Functional Mobility and Dynamic Postural Control Predict Overhead Handball Throwing Performance in Elite Female Team Handball Players

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Abstract

The relationship between dynamic postural control, functional mobility and team handball throwing performance, velocity and accuracy, is largely unknown. The hand reach star excursion balance test (HSEBT) is a full kinetic chain assessment tool of these factors. Specifically, L135 and R135 (extension) reaches elicit joint movement combinations similar to the cocking and acceleration phase, while the L45 and R45 (flexion) reaches elicit joint movement combinations similar to the follow-through. The purpose of this study was to determine if specific HSEBT reach measures correlate with team handball throwing performance. Eleven elite female team handball players (21.7 ± 1.8 years; 71.3 ± 9.6 kg; 1.75 ± 0.07 m) executed selected HSEBT reaches before performing five valid step-up overhead throws (1x1m target) from which throwing velocity (motion capture) and accuracy (mean radial error) were quantified. Significant relationships between HSEBT measures and mean radial error, but not throwing velocity were established. Specifically, extension composite scores (L135+R135) for the dominant (150.7 ± 17.4 cm) and non-dominant foot (148.1 ± 17.5 cm) were correlated with mean radial error ($p < 0.05$). Also, specific reaches on the dominant (L135: 87.4 ± 5.6 cm; R135: 63.4 ± 11.8 cm) and non-dominant (R135: 87.0 ± 6.1 cm) foot were correlated with throwing error ($p < 0.05$). The lack of significant findings to throwing velocity might be due to a ceiling effect of both L135 and R135 and of throwing velocity. We conclude that while there may be other reasons for handball players to train and test functional mobility and dynamic postural control as measured in the HSEBT, no beneficial effect on throwing performance should be expected in an elite group of handball players.

Key words: Ball games, ball velocity, throwing accuracy, dynamic postural control.

Introduction

In team handball, throwing performance is determined by both velocity and accuracy (Wagner et al., 2008). The combination of these two factors gives defenders and/or goalkeepers less time to parry the shot, thus increasing the likelihood of scoring (van Muijen et al., 1991). Throwing performance is the result of sequential muscle activation, torque generation, energy transfer, and a proximal to distal increase of joint angular velocities in the kinetic chain that starts in the lower extremities and progresses through the trunk into the upper extremities (Bartlett, 2000; Fradet et al., 2004; Herring and Chapman, 1992; Joris et al., 1985; Roach et al., 2013; van den Tillaar and Ettema, 2004; 2007; 2009b; Wagner et al., 2011; 2012; 2014). This sequential

behaviour requires joint mobility for both angular acceleration and deceleration throughout the kinetic chain. In their study Roach and Lieberman reported that limiting proximal kinetic chain segmental mobility by bracing decreased joint power generation throughout the kinetic chain, angular velocities, elastic storage of energy at the shoulder, and throwing velocity (Roach and Lieberman, 2014). Furthermore, kinetic chain analyses of handball throwing found correlations between throwing velocity and maximum joint positions obtained during the cocking and acceleration phase (van den Tillaar and Ettema, 2007; Wagner et al., 2011).

Since full kinetic chain analysis of throwing performance is an impractical field method, joint mobility is commonly quantified using traditional goniometric measurements of range of motion (ROM). However, only few studies explored the influence of ROM measurements on throwing performance, and non-significant findings have been reported (Schwesig et al., 2016; van den Tillaar, 2016). Furthermore, ROM measurements have an uncertain capacity to predict injuries (Andersson et al., 2018; Clarsen et al., 2014). These findings might be due to some inherent limitations of the traditional measurements. Firstly, ROM measurements might not be representative of the actual maximum joint movements attained during the throw (van den Tillaar, 2016). Secondly, goniometric measures only provide information about uniplanar and unidirectional movements of specific joints, and do not provide information about their role in the kinetic chain. Thirdly, in the current literature assessing throwing performance, goniometric measures are only applied to upper extremity joint movements, even if maximum trunk and pelvic rotations have been reported to also be important determinants (Wagner et al., 2011). Finally, passive goniometric tests have low neuromuscular demands. In fact, to the knowledge of the authors no studies so far explored the influence of dynamic postural control on team handball throwing performance. The lack of measurements that target kinetic chain assessment of both mobility and dynamic postural control are in contrast to current practice in the female Norwegian national team, where testing and training that integrate lower extremity, trunk and shoulder movements are used for both mobility and dynamic postural control purposes. Considering that this is the most successful female handball team in the past two decades (Olympic games, World Championships and European Championships several gold, silver and bronze medals), it is interesting to observe that such assessments are lacking in the literature.

Considering the aforementioned shortcomings, a study into the influence of mobility on throwing performance should include assessment of the full kinetic chain and impose greater neuromuscular demands. Thus, tests of functional mobility – i.e. the combination of range of motion (ROM) of multiple joints in ecological movements – might be an appropriate assessment strategy. The hand reach star excursion balance test (HSEBT) appears to be an appropriate test since the joint movements elicited by the different sub-tests (Eriksrud et al., 2018) are similar to those associated with overhead handball throwing (van den Tillaar and Ettema, 2007; Wagner et al., 2011). Other tests such as the star excursion balance tests (SEBT) (Gribble et al., 2012; Kang et al., 2015), upper quarter Y-balance test (UQYBT) (Gorman et al., 2012) and functional movement screen (FMS) (Butler et al., 2010; Cook et al., 2006) do not have this capacity.

Specifically, the HSEBT posterior overhead unilateral hand reach measurements quantify the ability to position the hand in space, which elicit hip, trunk and shoulder joint movements (Eriksrud et al., 2018) similar to those observed in the late cocking and acceleration phases of overhead throwing (van den Tillaar and Ettema, 2007; Wagner et al., 2011). Furthermore, the unilateral anterior diagonal hand reaches to floor level elicit combinations of hip, trunk and shoulder joint movements (Eriksrud et al., 2018) similar to those observed in the follow-through phase (van den Tillaar and Ettema, 2007; Wagner et al., 2011). In addition, the rotational reaches target transverse plane joint movements (Eriksrud et al., 2018) associated with the different phases of the throw (van den Tillaar and Ettema, 2007; Wagner et al., 2011).

Therefore, the purpose of this study was to determine the influence of functional mobility and dynamic postural control assessed through specific HSEBT reaches on team handball throwing performance. We hypothesized that specific HSEBT measures correlate with throwing accuracy or throwing velocity.

Methods

Participants

Thirteen Norwegian, international level, female handball players volunteered for the study, with eleven completing the entire protocol (age: 21.7 ± 1.8 years; weight: 71.3 ± 9.6 kg; height: 1.75 ± 0.07 m; wingspan: 1.74 ± 0.09 m). Debut in the elite division in Norway was 3.5 ± 1.9 years prior to participation in the study, and at the time of the study two players were on the national team while four different players participated in European club competitions. Exclusion criteria were musculoskeletal or neurological dysfunction or injury in the past six months, inability to participate in normal handball and throwing activities, and pain or discomfort reported during testing. All tests were done in the afternoon and participants were instructed to eat and hydrate as they would do for a regular practice. The committee for medical and health research ethics in Norway (2014/2230) and the Norwegian Centre for Research Data (40934) had reviewed and approved the study. Measurements were carried out according to the principles described in the Declaration of Helsinki. All

subjects were given written and verbal information about the experimental risks associated with the study and signed an informed consent form prior to participation. Testing was done mid to late season.

Experimental design

This was a descriptive and cross-sectional cohort study for comparison of HSEBT reaches with overhead throwing performance (ball velocity and accuracy). Specifically, HSEBT reaches that represent joint movements associated with the different phases of the overhead handball throw, cocking, acceleration and follow-through, were selected. The unilateral posterior overhead reaches (L135 and R135) were tested since hip, trunk and upper extremity joint movements and positions assumed in these reaches (Eriksrud et al., 2018) are similar to those observed in the cocking and acceleration phase in the same joints (van den Tillaar and Ettema, 2007; Wagner et al., 2011). Similarly, the unilateral anterior diagonal reaches to floor level (L45 and R45) were tested since hip, trunk and upper extremity joint movements and positions assumed in these reaches (Eriksrud et al., 2018) are similar to those observed in the follow-through phase in the same joints (van den Tillaar and Ettema, 2007; Wagner et al., 2011). Furthermore, Left (LROT) and right (RROT) rotational reaches were done to target the hip and trunk rotations associated with the three phases of the throw (van den Tillaar and Ettema, 2007; Wagner et al., 2011).

Anthropometric measurements and limb dominance

Prior to testing, body height and weight were obtained using a Seca model 217 stadiometer and a Seca flat scale (Seca GmbH. & Co. Hamburg, Germany). A standard tape measure was used to measure wingspan (tip of middle finger to middle finger with shoulder abducted to 90 degrees in standing), arm length (acromion to tip of middle finger with shoulder abducted to 90 degrees in standing) and leg length (greater trochanter to floor in standing). The dominant hand was defined as the throwing hand, while the dominant foot was defined as the pivot foot in the 8-meter throw with run-up.

Warm-up

All subjects performed a 15-minute standardized warm-up. The general warm-up (10 minutes) consisted of jogging, different shuffle runs, skipping and dynamic stretching focusing on full body movements in all three planes of motion. The handball-specific part (5 minutes) consisted of throwing at a large target (wall) with a gradual increase in velocity with the last 2-3 throws at maximum throwing velocity.

Throwing protocol

A throwing target was indicated on a high-jump mat (2 m x 3 m) placed vertically in front of a handball goal in order to protect lab equipment. Based on different protocols previously used in handball throwing studies (van den Tillaar and Ettema, 2003; Wagner et al., 2014) sports tape was used to define a +-shaped throwing target (1 m x 1 m). For right-handed subjects the target was placed 0.1 m below the crossbar at the right side of the goal's midline.

This was mirrored for the left-handed subjects (van den Tillaar and Ettema, 2003). An International Handball Federation standard size women's handball (Select AS, Glostrup, Denmark) was used for all throws. A three-step run-up throw from 8 m was used, since this throw is frequently used in team handball when throwing from the backcourt position (Wagner et al., 2012). All subjects were given the following instructions: "Throw the ball as hard as you can and hit the target" (van den Tillaar and Ettema, 2003). There was a one-minute rest period between throws. The subjects continued throwing until five valid throws (inside the target) were obtained.

Dynamic postural control and functional mobility

Dynamic postural control and functional mobility were assessed using the HSEBT, which has been reported to be valid and reliable (Eriksrud et al., 2017). The original HSEBT consists of 10 hand reaches on each foot (stance foot) with a toe-touch of the opposite foot. Reach direction definitions and procedures are described in detail elsewhere (Eriksrud et al., 2017), but are summarized here for clarity. HSEBT reaching directions are defined from the anatomical neutral position as follows: direction (i.e.: anterior (A); posterior (P)), side of body (left (L); right (R)), angle at 45° increments from anterior (0°) to posterior (180°) and movement (rotation (ROT)). Reaches along the 8 horizontal reach vectors (A0, R45, R90, R135, P180, L135, L90 and L45) are horizontal reaches (HR) and measured in centimeters (cm), while the two rotational reaches (LROT, RROT) are measured in degrees (°). Of the horizontal reaches, the diagonal reaches (L45, R45,

L135, R135) were selected based on the similarity of elicited hip, trunk and shoulder joint movements and positions (Eriksrud et al., 2018) to the different phases of the throw (van den Tillaar and Ettema, 2007; Wagner et al., 2011) as described previously. Based on sagittal plane hip movements at maximum reach position, L45 and R45 are considered flexion while L135 and R135 are extension movement patterns. In addition, left (LROT) and right rotational reaches (RROT) were performed to target full body rotation. All HSEBT reaches were performed in the same order on a testing mat specifically designed to guide and perform measurements. Specifically, the testing mat identifies the eight horizontal reaching directions with imprinted marks at 2 cm intervals, and nine concentric circles (at 10 cm intervals) with marks at 5-degree intervals (Athletic Knowledge Nordic AB, Stockholm, Sweden). A plumb line (L135 and R135) and a stick (LROT and RROT) were used to project the position of the middle digit of the reaching hand(s) to the mat. Images of HSEBT tests and maximum reach positions are presented in Figure 1 and 2. Three to five practice trials were allowed, after which three valid reaches were recorded and the maximum value used for analysis. Trials were discarded if the procedures were not followed. Composite scores (CS) were calculated as the sum of horizontal reaches for the following: dominant foot (CS_{dom}), non-dominant foot ($CS_{non-dom}$), dominant foot flexion movement patterns (CS_{dom_flex}), non-dominant foot flexion movement pattern ($CS_{non-dom_flex}$), dominant foot extension movement pattern (CS_{dom_ext}) and non-dominant foot extension movement pattern ($CS_{non-dom_ext}$).

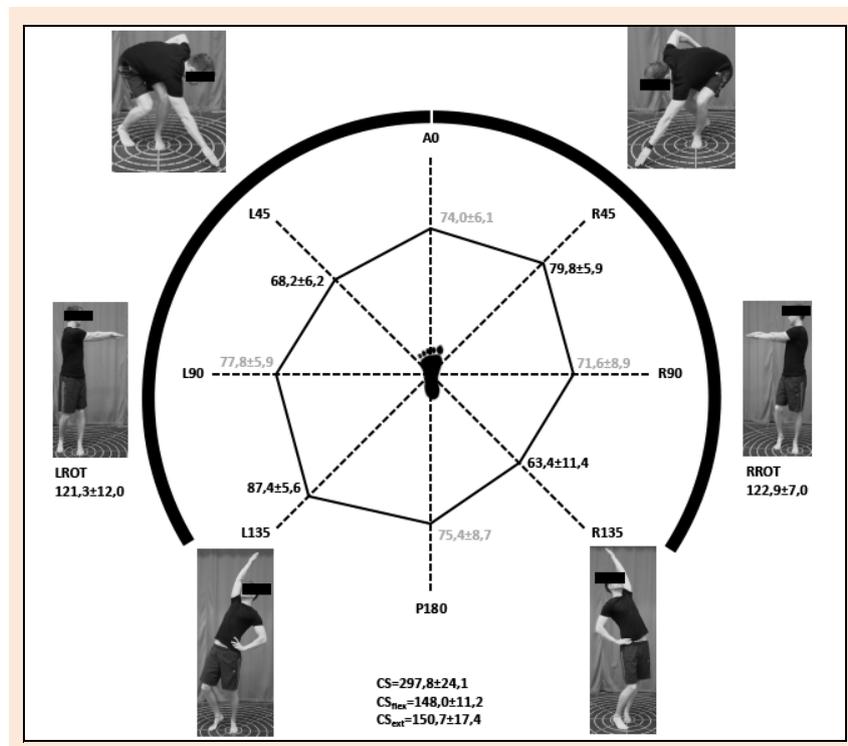


Figure 1. Horizontal and rotational reaches HSEBT dominant leg with accuracy comparisons. Visual representations of the execution of the horizontal and rotational reaches (photographs) on the left foot (9/11 subjects left foot dominant) with mean (\pm SD) reach distances (cm, °) for observed (black) and calculated (grey) HSEBT reaches and CS (sum of horizontal reaches), CS_{flex} (sum flexion movements patterns) and CS_{ext} (sum extension movement patterns) with their correlations (r , * $p < 0.05$)

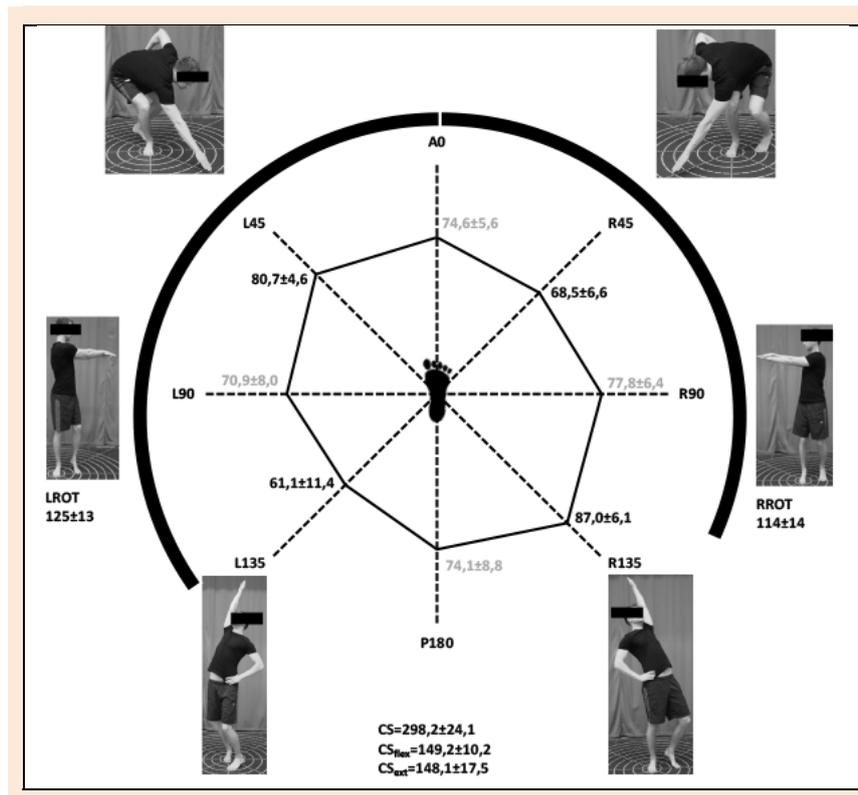


Figure 2. Horizontal and rotational reaches HSEBT non-dominant leg with accuracy comparisons. Visual representations of the execution of the horizontal and rotational reaches (photographs) on the left foot (2/11 subjects right foot non-dominant) with mean (\pm SD) reach distances (cm, $^\circ$) for observed (black) and calculated (grey) HSEBT reaches and CS (sum of horizontal reaches), CS_{flex} (sum flexion movements patterns) and CS_{ext} (sum extension movement patterns) with their correlations (r , * $p < 0.05$)

Kinematic and video analysis

Five Oqus-4 cameras (Qualisys AB, Gothenburg, Sweden) were used to collect kinematic data (recorded at 480 Hz) from five reflective markers (20 mm ϕ) attached to the ball (two markers opposite each other to determine the center of the ball), throwing hand (head of the intermediate phalanx of the third digit) and pelvis (highest point left and right iliac crest). Marker data was filtered (2nd order Butterworth low pass filter with 15Hz cut-off frequency), then throwing velocity ($\text{m}\cdot\text{s}^{-1}$), was calculated as the average velocity between frames 3 and 8 after time (t_0) (frame of maximum acceleration between the marker on the third digit and the center of the ball (midpoint between the two ball markers), which increases abruptly at ball release (van den Tillaar and Ettema, 2007). Entry velocity ($\text{m}\cdot\text{s}^{-1}$) was defined as the maximum velocity of the midpoint between the two pelvic markers 3 and 100 ms prior to t_0 . Both throwing and entry velocity were calculated for all throws using Matlab (Mathworks Inc, Natick MA, USA). Accuracy of all throws was calculated from video analysis using a video camera (Basler acA2000 – 165uc video camera (Baser AG, Ahrensburg, Germany)) placed 12 m away from the target at a height of 2 m. Mean radial error was used as the accuracy measurement and defined as the average of the absolute distance from the center of the ball to the center of the target (van den Tillaar and Ettema, 2003) using Dartfish (Dartfish, Fribourg, Switzerland). The number of throws used by each subject to reach five valid throws was recorded but only the valid throws were used for analysis.

Statistical analysis

Descriptive statistics (mean and standard deviation (SD)) were calculated in Excel for Mac OS 10.10.5 (Apple Inc., Cupertino, CA, USA), version 14.4.8 (Microsoft Corp., Redmond, WA, USA). All other statistical tests were done using IBM SPSS version 21.0 (IBM, Armonk, NY, USA). Normality of the data was assessed using the Shapiro-Wilk test ($p < 0.05$). Pearson correlation analysis (two-tailed) was done to determine the relationship between throwing velocity, accuracy, number of attempts and tests of dynamic postural control (cm, $^\circ$ and CS). Linearity of the relationships between these variables were assessed using visual inspection of scatter plots. Outliers were determined and removed from the analysis based on adding or subtracting the interquartile range multiplied by 2.2 from the mean of measurements (Hoaglin and Iglewicz, 1987). Dynamic postural control tests are presented based on the dominant foot and hand respectively. Since 9 of 11 players were left foot dominant, left foot reach definitions were used for the presentation of the HSEBT results.

Results

The throwing performance of the participants was as follows: entry velocity ($3.1 \pm 0.5 \text{ m}\cdot\text{s}^{-1}$), throwing velocity ($22.8 \pm 1.9 \text{ m}\cdot\text{s}^{-1}$), accuracy ($0.32 \pm 0.09 \text{ m}$), and number of throws (8.8 ± 3.0) (average \pm SD). Reach measurements and composite scores for the dominant and non-dominant foot are presented in Table 1 and Figure 1 and 2. All independent and dependent variables were normally distributed (Shapiro Wilk > 0.05). There was no throwing velocity and

accuracy trade-off ($r = 0.062$, $p = 0.856$). No significant correlations between number of throws and throwing velocity ($r = -0.267$, $p = 0.428$) and accuracy and number of throws ($r = 0.330$, $p = 0.322$) were observed. No significant correlations between throwing velocity and individual HSEBT reaches or composite scores were observed (Table 1) with small coefficients of determination ($R^2 = 0.0004$ to 0.11) (Figure 3). However, correlations between HSEBT composite scores and mean radial error were significant for the dominant ($CS_{dom} r = 0.622$, $p < 0.05$) and approached significance for the non-dominant foot ($CS_{non-dom} r = 0.584$,

$p = 0.059$). Significant correlations between mean radial error and extension movement pattern composite scores for both the dominant foot ($CS_{dom_ext} r = 0.756$, $p < 0.05$) and non-dominant foot ($CS_{non-dom_ext} r = 0.656$, $p < 0.05$) were observed (Table 1). Both the L135 ($r = 0.725$, $p < 0.05$) and R135 ($r = 0.698$, $p < 0.05$) reaches on the dominant foot and the R135 reach ($r = 0.839$, $p < 0.05$) on the non-dominant foot were significantly correlated with the mean radial error. These significant findings corresponded with greater coefficients of determination ranging from 0.34 to 0.70 (Figure 4).

Table 1. Correlations HSEBT measurements and throwing performance.

Measurement	Measurement (mean±SD)	Throwing velocity	Mean radial error	
Dominant	R45 (cm)	79.8 ± 5.9	.315 (p=.345)	.124 (p=.717)
	L45 (cm)	68.2 ± 6.2	.205 (p=.546)	.488 (p=.128)
	L135 (cm)	87.4 ± 5.6	.126 (p=.713)	.725 (p=.012)*
	R135 (cm)	63.4 ± 11.8	.275 (p=.413)	.698 (p=.017)*
	RROT (°)	122.9 ± 7.0	-.242 (p=.473)	.128 (p=.780)
	LROT (°)	121.3 ± 12.0	-.551 (p=.079)	.072 (p=.834)
	CS (cm)	297.8 ± 24.1	.326 (p=.328)	.622 (p=.041)*
	CS _{flex} (cm)	148.0 ± 11.2	.280 (p=.404)	.334 (p=.315)
	CS _{ext} (cm)	150.7 ± 17.4	.243 (p=.472)	.756 (p=.007)*
Non-dominant	R45 (cm)	68.5 ± 6.6	-.020 (p=.953)	.361 (p=.276)
	L45 (cm)	80.7 ± 4.6	.141 (p=.679)	.009 (p=.979)
	L135 (cm)	61.1 ± 11.4	.111 (p=.745)	.483 (p=.132)
	R135 (cm)	87.0 ± 6.1	-.062 (p=.856)	.839 (p=.001)*
	RROT (°)	114.1 ± 10.3	-.064 (p=.852)	-.075 (p=.826)
	LROT (°)	125.2 ± 10.1	-.393 (p=.232)	.226 (p=.503)
	CS (cm)	298.2 ± 24.1	.026 (p=.939)	.584 (p=.059)
	CS _{flex} (cm)	149.2 ± 10.2	.050 (p=.883)	.237 (p=.483)
	CS _{ext} (cm)	148.1 ± 17.5	.055 (p=.873)	.656 (p=.028)*

* $p < 0.05$. L=Left; R=Right; R45=Right anterolateral (45°) reach; R135=Right posterolateral (135°) reach; L135=Left posterolateral (135°) reach; L45=Left anterolateral (45°) reach; RROT=Right rotational reach; LROT=Left rotational reach

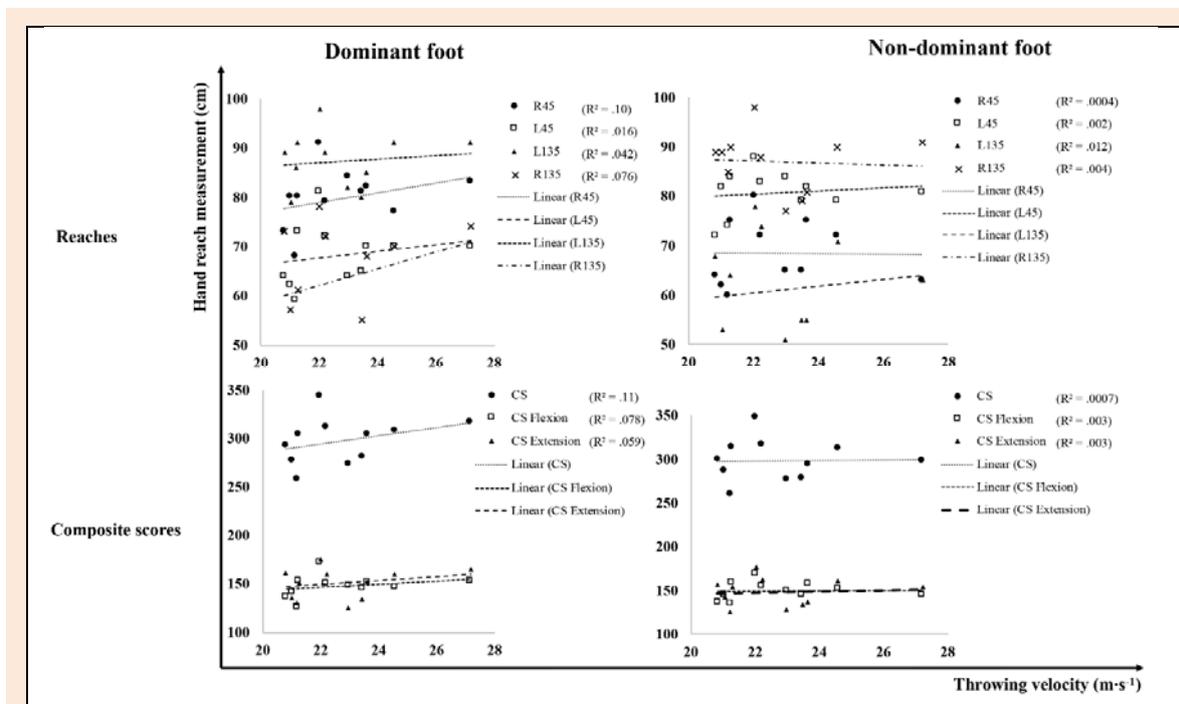


Figure 3. The relationship between hand reach measurements and throwing velocity shown for all subjects for specific hand reaches and composite scores (lines) for the dominant and non-dominant foot (columns). Specific reaches and composite scores identified by symbols with their respective coefficients of determination (R^2).

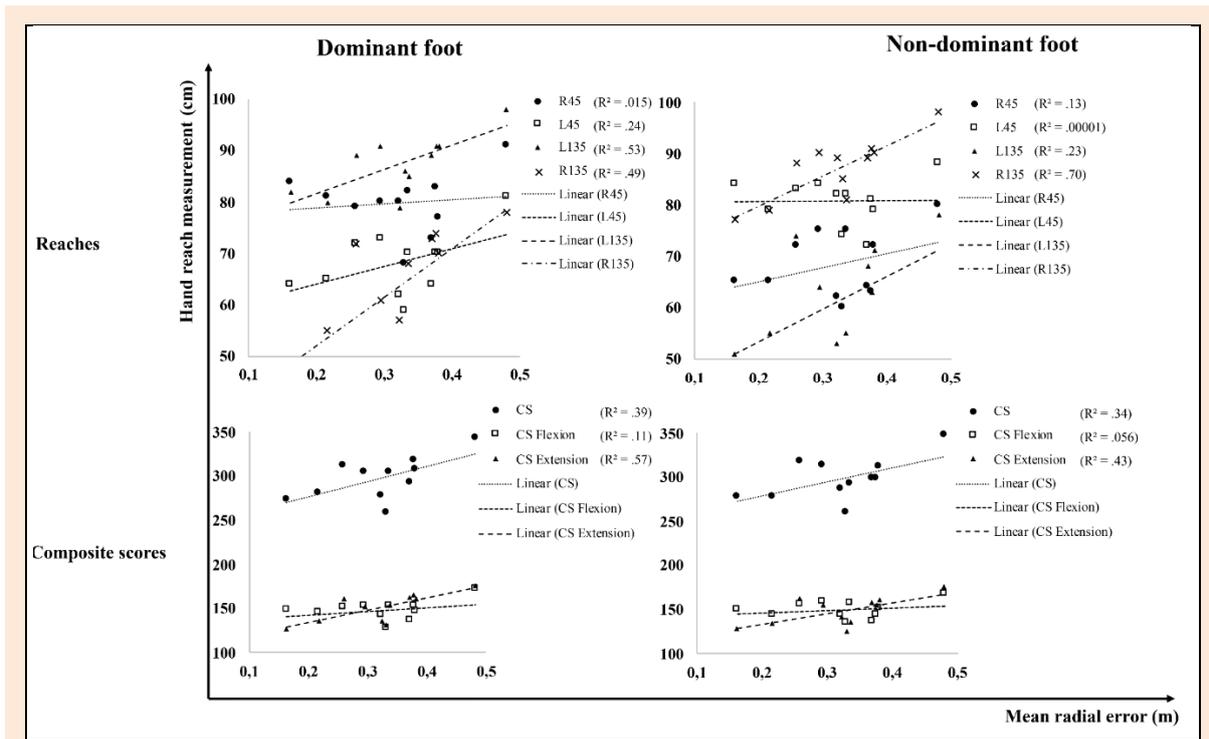


Figure 4. The relationship between hand reach measurements and throwing accuracy shown for all subjects for specific hand reaches and composite scores (lines) for the dominant and non-dominant foot (columns). Specific reaches and composite scores identified by symbols with their respective coefficients of determination (R^2).

Discussion

The current study could not confirm the hypothesized positive relationship between HSEBT reaches and throwing performance. Specifically, no correlations were found between HSEBT reaches and throwing velocity and HSEBT reaches correlated negatively with throwing accuracy (positive correlation with mean radial error). These results suggest that within the group of world-class players tested in the current study, increased dynamic joint mobility, as assessed through the HSEBT, is not a beneficial factor for throwing performance. Compared to other athletes that were tested so far (Eriksrud et al., 2017; 2018) the athletes in the current study showed unusually large reach distances. Therefore we speculate that a ceiling effect could explain that no correlation was found with throwing velocity, while the negative relationship with throwing accuracy might indicate that some of the players may have surpassed an optimum in joint mobility.

A secondary result of the current study was that there was neither a trade-off, nor a correlation between throwing velocity and throwing accuracy. This is a finding that agrees well with previous observations (Garcia et al., 2013; van den Tillaar and Ettema, 2003; 2006).

Throwing velocity

The throwing velocities measured in the current study are comparable to what has been reported elsewhere for elite female handball players (Granados et al., 2007; 2008; Vila et al., 2012). Tests of functional mobility and dynamic postural control, both HSEBT reaches and composite scores, did not correlate with throwing velocity. Hip extension, pelvic rotation, trunk rotation and extension are joint

movements associated, on the one hand, with the approach, cocking and acceleration phase of the throw (van den Tillaar and Ettema, 2007; Wagner et al., 2011), and on the other hand, with the different posterior reaches (Eriksrud et al., 2018). Furthermore, Wagner and co-workers found that maximum trunk and pelvic rotation during the throw were correlated with throwing velocity (Wagner et al., 2011). Therefore it seemed plausible to expect a correlation between HSEBT results and throwing velocity. Our findings, however, did not support this assumption. Considering that all subjects were elite level handball players, they could all have had sufficient joint mobility to generate high throwing velocities (ceiling effect). In fact, comparisons of L135 and R135 reach measurements for both the dominant and non-dominant foot to available reference data showed that the handball players have reach measurements greater than established minimal detectable change (Eriksrud et al., 2017). However, such differences could not be observed for flexion and rotational movements patterns (Eriksrud et al., 2017). These comparisons might indicate that the players in the current study have sufficient functional mobility and dynamic postural control associated with the cocking and acceleration phase for the generation of high throwing velocities.

Based on current and previous findings, it appears that ROM, functional mobility and dynamic postural control measurements do not predict throwing velocity. Thus, mobility and dynamic postural control measurements should perhaps be analysed in combination with measures of other neuromuscular qualities to better understand the underlying factors influencing throwing velocity. Muscular strength and power are more studied than mobility and have been found to be significantly correlated with throw-

ing velocity (Chelly et al., 2010; Cherif et al., 2016; Debanne and Laffaye, 2011; Fleck et al., 1992; Gorostiaga et al., 2005; Granados et al., 2007; Machado et al., 2013; Marques et al., 2007). Specifically, power tests (kneeling medicine ball throw) and strength and power training (overhead medicine ball throwing) that target joint movements similar to those observed in the posterior overhead reaches (shoulder flexion, hip and trunk extension) have been found to be correlated with throwing velocity (Debanne and Laffaye, 2011; Hermassi et al., 2015).

Throwing accuracy

The throwing accuracy observed in the current study (0.32 ± 0.09 m) was comparable with previous findings (van den Tillaar and Ettema, 2003; 2006; Wagner et al., 2010; 2011; Zapartidis et al., 2007). Unlike throwing velocity, accuracy has not received the same attention in the literature. The effect of instructions (Garcia et al., 2013; van den Tillaar and Ettema, 2003; 2006), age and sex (Gromeier et al., 2017), fatigue (Nuno et al., 2016; Zapartidis et al., 2007), performance level (Rousanoglou et al., 2015; van den Tillaar and Ettema, 2006), temporal constraints (Rousanoglou et al., 2015), throwing techniques (Wagner et al., 2010) and laterality (van den Tillaar and Ettema, 2009a) on throwing accuracy have been explored. However, only two studies explored the influence of neuromuscular qualities, such as strength and power, on accuracy (Raeder et al., 2015; Zapartidis et al., 2007). Accuracy was found to decrease with fatigue, while shoulder strength and throwing velocity did not (Zapartidis et al., 2007), indicating that there is no relationship between shoulder strength and throwing accuracy. This finding was supported by Raeder et al. (2015), who reported medicine ball training improved strength, power, velocity, but not throwing accuracy. To the best of the authors' knowledge no studies so far explored the influence of clinical tests of mobility or dynamic postural control on accuracy. In addition, mobility data available from kinematic studies, maximum joint positions obtained during the cocking and acceleration phase or magnitude of joint movements utilized during the throw, have been used to analyze throwing velocity (van den Tillaar and Ettema, 2007; Wagner et al., 2010; 2011) but not accuracy, with one exception (Urban et al., 2015). Urban and co-workers showed that decreased movement kinematics from stable to unstable throwing conditions lead to decreased throwing velocity with no influence on accuracy (Urban et al., 2015). However, the population studied had a much lower throwing velocity ($16 \text{ m}\cdot\text{s}^{-1}$) than what was observed in the current study. Furthermore, the influence of mobility and dynamic postural control on accuracy in other comparable overhead and throwing sports has also received little attention. In baseball, static stretching did not influence accuracy (Haag et al., 2010), while better static balance in baseball (Marsh et al., 2004) and lacrosse (Marsh et al., 2010) improved accuracy (Marsh et al., 2010).

Considering the limited information available on the influence of dynamic postural control and functional mobility on throwing accuracy current findings provide

valuable information on this important throwing performance factor. Our findings showed that greater posterior overhead hand reach measurements were correlated with lower throwing accuracy. One speculative interpretation of this finding might be that posterior overhead reaches quantify proprioceptive and balance demands associated with throwing. Measures of proprioception are correlated with successful basketball free-throw performance (Sevrez and Bourdin, 2015), but not throwing accuracy in baseball (Freeston et al., 2015) or lacrosse (Marsh et al., 2010). Based on their findings, Freeston et al. (2015), argued that proprioception of the entire kinetic chain should be assessed since proprioception of the shoulder joint in isolation did not correlate with throwing accuracy. If proprioception is measured by the HSEBT and more accurate throwers have better proprioception, then lower posterior overhead reach measurements represent better, or a better use of proprioceptive information. It might be that some players stopped at a maximum reach position at a lower reach measurement based on proprioceptive input from different joints or at a safer margin to limits of stability. Newton established that hand reaches have directional specific limits of stability (Newton, 2001) whereby it might be that more accurate throwers control these limits of stability in the posterior directions with a greater margin safety for stability purposes.

Limitations

One limitation – or strength, depending on the viewpoint – of the current study is the high performance level of the recruited handball players. Generalization of the findings in the current study beyond an international level female team handball population should be done cautiously. Exploration of how different performance levels, age and sex influence the relationship between HSEBT measurements and throwing performance seems warranted.

Clinical perspective

Full kinetic chain testing of functional mobility and dynamic postural control using the HSEBT might have different applications in team handball beyond assessment of throwing performance. Shoulder problems are one of the injury areas with the greatest impact on participation in team handball (Clarsen et al., 2014). Isolated tests of shoulder mobility have a variable capacity to predict shoulder injuries (Andersson et al., 2018; Clarsen et al., 2014). The HSEBT may offer important clinical information by addressing full kinetic chain movement tasks. Specifically, dynamic positioning of the scapula to stabilize the glenohumeral joint is dependent on segmental coordination of the entire kinematic chain (Kibler and Sciascia, 2016), which could be addressed by the HSEBT.

Conclusion

Overhead team handball throwing velocity and accuracy in elite female players were not beneficially influenced by functional mobility and dynamic postural control as measured by the HSEBT. There may be other reasons why elite

handball players may want to train and test functional mobility and dynamic postural control utilizing the kinetic chain as in the HSEBT, particularly with regard to injury prevention; however, the current study suggests that no beneficial effect on throwing performance should be expected in an elite population.

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Key points

- This study is the first to explore the influence of dynamic postural and functional mobility on team handball throwing performance.
- Dynamic postural control and functional mobility as measured by the HSEBT did not positively affect throwing performance in an elite female population.
- Neither a trade-off nor a correlation between throwing velocity and accuracy were observed.
- The influence of different performance levels, age and sex on the relationship between HSEBT measurements and throwing performance should be explored.

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