

Research article

Performance and kinematics of various throwing techniques in team-handball

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Abstract

In team-handball competition, the players utilize various throwing techniques that differ in the lower body movements (with and without run-up or jump). These different lower body movements influence changes in the upper body movements and thus also affect the performance. A comprehensive analysis of 3D-kinematics of team-handball throws that may explain these differences in performance is lacking. Consequently, the purpose of this study was (1) to compare performance (ball velocity and throwing accuracy) between the jump throw, standing throw with and without run-up, and the pivot throw; (2) to calculate the influence of kinematic parameters to ball velocity; and (3) to determine if these four throwing techniques differ significantly in kinematics. Three-dimensional kinematic data (angles, angular velocities and their timing, ball velocity and velocity of the center of mass) of 14 elite team-handball players were measured using an 8 camera Vicon MX13 motion capture system (Vicon, Oxford, UK), at 250 Hz. Significant difference was found between the four throwing techniques for ball velocity ($p < 0.001$), maximal velocity of the center of mass in goal-directed movement ($p < 0.001$), and 15 additional kinematic variables ($p < 0.003$). Ball velocity was significantly impacted by the run-up and the pelvis and trunk movements. Depending on floor contact (standing vs. jump throws), elite players in the study used two different strategies (lead leg braces the body vs. opposed leg movements during flight) to accelerate the pelvis and trunk to yield differences in ball velocity. However, these players were able to utilize the throwing arm similarly in all four throwing techniques.

Key words: Ball games, biomechanics, ball velocity, throwing accuracy.

Introduction

In team-handball, the offensive players attempt to throw a ball on goal from a position without being tackled or obstructed by the opposing defensive players. This is accomplished using tactical components of passing the ball and utilizing different throwing techniques. In competition, 73-75% of all throws during the game constitute jump throws, followed by the standing throw with run-up (14-18%), penalty throw (6-9%), diving throw (2-4%) and direct free throw (0-1%) (Wagner et al., 2008). Run-up is limited to the jump throw and standing throw with run-up. These techniques are used to increase the horizontal velocity, making it difficult for the defensive player to tackle and potentially enabling a higher ball velocity.

Recent studies analyzing the throwing movement in team-handball suggest that different throwing techniques result in different ball velocities (Fradet et al.,

2004; Gorostiaga et al., 2005; Sibila et al., 2003; van den Tillaar and Ettema, 2004; 2007; Wagner and Müller, 2008; Wagner et al., 2010a). Bayios and Boudolos (1998) described differences in ball velocity and the throwing accuracy of Greek elite team-handball players revealing that greatest ball velocity was achieved in the standing throw with run-up ($26.3 \pm 3.2 \text{ m}\cdot\text{s}^{-1}$) rather than the standing throw without run-up ($23.5 \pm 2.2 \text{ m}\cdot\text{s}^{-1}$) and jump throw ($22.7 \pm 2 \text{ m}\cdot\text{s}^{-1}$). Comprehensive kinematic analysis of the standing throw in team-handball (van den Tillaar and Ettema, 2004; 2007; Wagner and Müller, 2008) has shown that the internal shoulder rotation angular velocity at ball release, maximal elbow extension and the timing of the maximal pelvis angle are important contributors to the ball velocity. Measuring kinematics of jump throw in elite vs. low level players in team-handball, Wagner et al. (2010a) found significant differences in ball velocity, maximal trunk internal rotation and trunk flexion, as well as trunk flexion and shoulder rotation angular velocity at the ball release. However, it is clearly observable (Figure 1A-D) that these four throwing techniques differ in the lower body movement. The standing throw (Figure 1A) involves keeping the lead foot on the floor during the throw and is typical for the penalty throw in team-handball. In the standing throw with run-up (Figure 1B), one foot is planted on the floor after the run-up. The jump throw (Figure 1C) involves executing a vertical jump off one leg at take-off after the run-up. In the pivot throw (Figure 1D), the thrower performs a vertical jump from both legs at take-off after turning. Based on the observable differences (Figure 1A-D) it should be explored how planting on the floor (stemming in the standing throw with run-up) vs. vertical jumping with one or two legs at take-off influence the throwing movement and, ultimately, ball velocity.

The jump throw, standing throw with and without run-up and pivot throw are fundamental skills in team-handball; however, a study compares differences in performance and determines the influence of different kinematics to ball velocity is lacking. The more specific aims of this study were: (1) to measure differences in performance (ball velocity and throwing accuracy) between the jump throw, the standing throw with and without run-up, and pivot throw; (2) to determine the influence of different kinematics to ball velocity; and (3) to explain how these differences influence the energy transfer to the ball. The findings of the study should determine how different movements in the different throwing techniques influence ball velocity. This will provide important information to team-handball coaches and athletes alike.

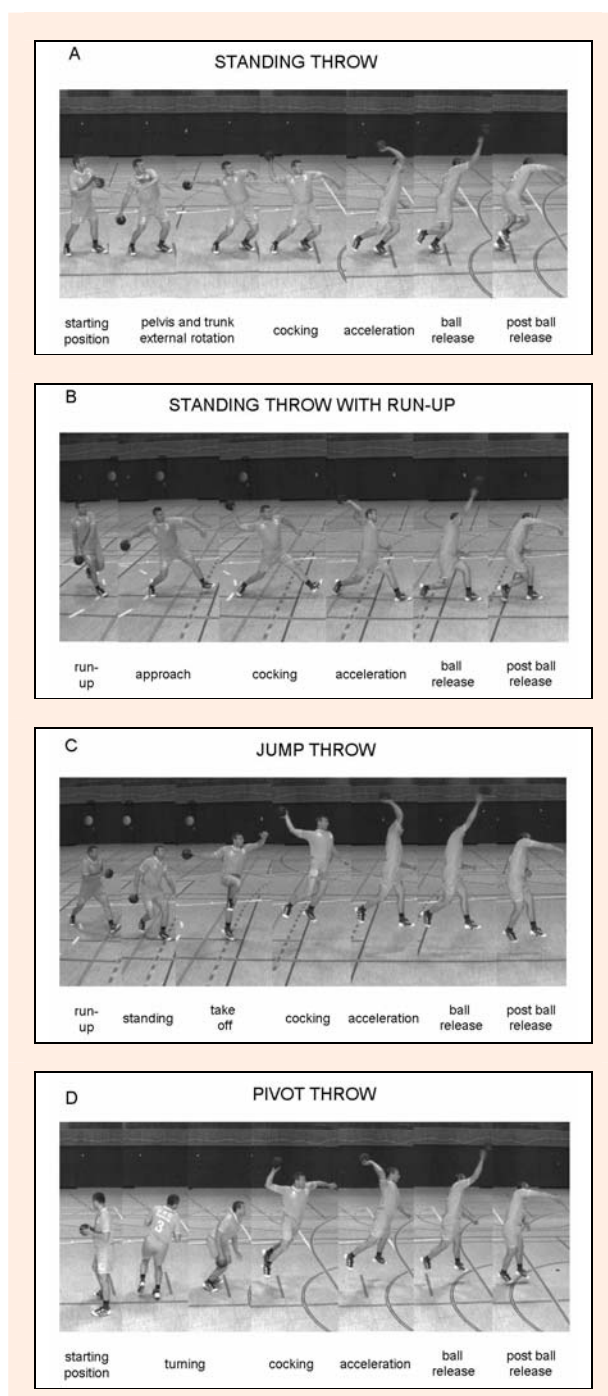


Figure 1. Team-handball picture sequence of the standing throw (A), standing throw with run-up (B), jump throw (C), and pivot throw (D).

Based on previous studies in team-handball throwing (van den Tillaar and Ettema, 2004; 2007; Wagner and Müller, 2008; Wagner et al., 2010a; 2010b), we expected to find significant differences in throwing performance between the different throwing techniques that may be influenced by the velocity of the centre of mass in goal-directed movement, and lower and upper body kinematics.

Methods

Participants

Fourteen male elite handball players (age: 22.9 ± 4.2 yrs;

height: 1.85 ± 0.07 m; mass: 82.4 ± 11.1 kg; training experience: 10.8 ± 3.8 yrs), playing in the first, second and third Austrian Handball, first German and Spanish Handball League volunteered to participate in the present study. All participants were physically healthy, in good physical condition and reported no injuries during the time of the study. The study was approved by the local ethics committee. Written informed consent was obtained from all participants before testing. To insure that the results of the study were not influenced by the playing position of the participants, we recruited players from all playing positions (7 backcourt, 5 wing, 2 pivot).

Test protocol

After a general and a handball specific warm up of 20 min, the participants were asked to perform 10 valid (for each throwing technique) standing throws without run-up, standing throws with run-up, vertical jump throws, and pivot throws (jump throw take off with both legs after turning). The ranking order of the four throwing techniques was randomized for each participant. After five valid throws the participants changed the throwing technique and repeated this procedure a second time to ensure that fatigue did not influence the results. To measure throwing performance we used a square of 1×1 m at about eye level (1.75 m high) and instructed the participants to throw the ball with a maximal ball velocity to the center of the target. Horizontal distance between the ball and the target at ball release was about 8 m, except for the standing and pivot throw (about 7 m). In team-handball competition (Wagner et al., 2008) the standing (penalty throw) and pivot throw were used at distances near the goal (6–7m), whereas the standing throw with run-up and jump throw were used from backcourt players when throwing from a greater distance (8–12m). In the testing situation we decided to choose different distances to the goal (7 vs. 8m) which enabled conditions similar to those in competition, although this implicates different throwing angles to the target. A throw was valid if the ball did not deviate from the center of the target in the horizontal and vertical directions by more than 0.5 m, and if all data were recorded without failure. This was done until 10 valid throws were recorded for each of the four throwing techniques for each participant (to measure the percentage of missed throws all throws of each throwing technique were counted). To ascertain that only the best throws of the four throwing technique of every participant were calculated, the six throws with the greatest ball velocity for every participant were used for statistical analysis.

Kinematic analysis and angle calculations

The experimental set-up consisted of an eight camera Vicon MX13 motion capture system (Vicon Peak, Oxford, UK), at 250 Hz. For kinematic analysis, 39 reflective marker of 14 mm diameter were affixed to specific anatomical landmarks (Plug-In Gait Marker Set, Vicon Peak, Oxford, UK) for every participant. Three-dimensional (3D) trajectories of the 39 markers were analyzed utilizing Nexus software (Nexus 1.3, Vicon, Oxford, UK) and filtered with a Woltring filter (Woltring, 1986). To calculate the joint positions, a 3D-model (Plug-In Gait Model, Vicon Peak, Oxford, UK) was used

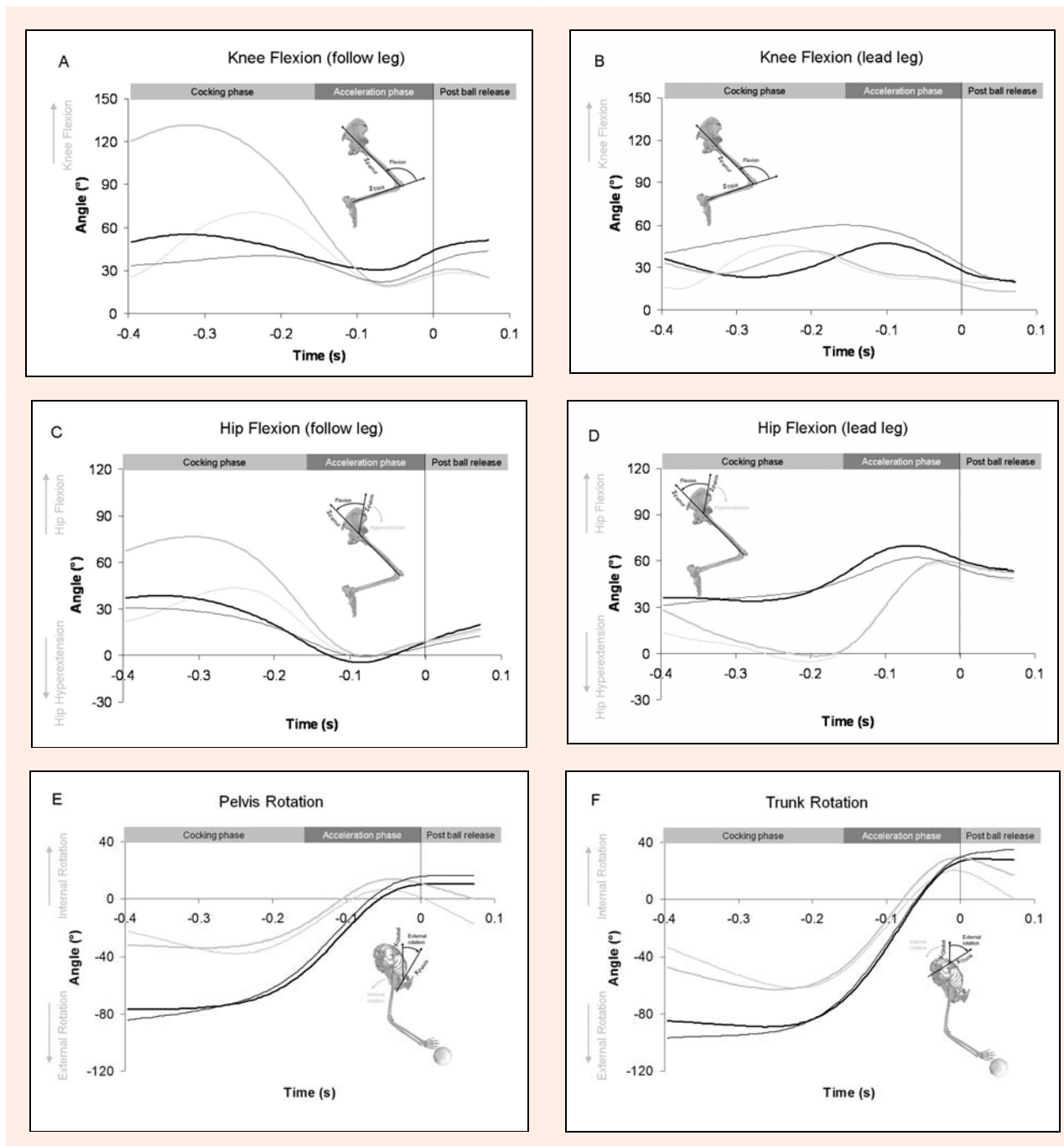


Figure 2. Knee flexion follow leg (A), knee flexion lead leg (B), hip flexion follow leg (C), hip flexion lead leg (D), pelvis rotation (E), and trunk rotation (F) mean angle curves in the standing throw with (thick black line) and without run-up (thin black line), jump throw (thick grey line), and pivot throw (thin grey line).

(Davis et al., 1991), dividing the body into upper and lower body models. The model used was identical to that of Wagner et al. (2009) who analyzed the spike movement in volleyball and Wagner et al. (2010a) who analyzed the jump throw in team-handball.

For joint angle calculation, we used the same method as described in detail by Wagner et al. (2009; 2010a). Joint angles were calculated by the relative orientation of the proximal and distal segments. The joint flexion angles (knee, hip, shoulder and elbow flexion, Figure 2A, B, C, D, 4A and C) were used to determine the longitudinal axes of the proximal and distal segments. The shoulder internal-external rotation angle (Figure 4B) was

defined as the rotation of the humerus along the longitudinal axis of the humerus. A positive value corresponds to internal shoulder rotation. Pelvis/trunk rotation angles (Figure 2E, F) were calculated between the sagittal axis of the pelvis/trunk and those of the sagittal axis of the measuring field and the trunk flexion (Figure 3) between the projected sagittal trunk axis and the sagittal axis of the measuring field.

Variable calculations and phase classification

Linear and angular velocities were calculated using the 5-point central differential method (Van den Tillaar and Ettema, 2003). Ball release point and ball velocity were

determined as described in detail by Wagner et al. (2010a). For a detailed discussion of the results, we separated the throwing movements into three different phases, two phases before ball release (cocking and acceleration phase) and one after ball release (post ball release). Cocking phase was defined from the beginning (400ms before ball release) to the beginning of acceleration phase. We termed the acceleration phase as the time lag between the moment when the angular acceleration of the trunk rotation became maximal to ball release, and post ball release from ball release to the end (100ms after ball release). The total time frame was chosen from 400ms before to 100ms post ball release, because that was sufficient to calculate all relevant variables (Fradet et al., 2004; Van den Tillaar and Ettema, 2007; Wagner et al., 2010a; 2010b).

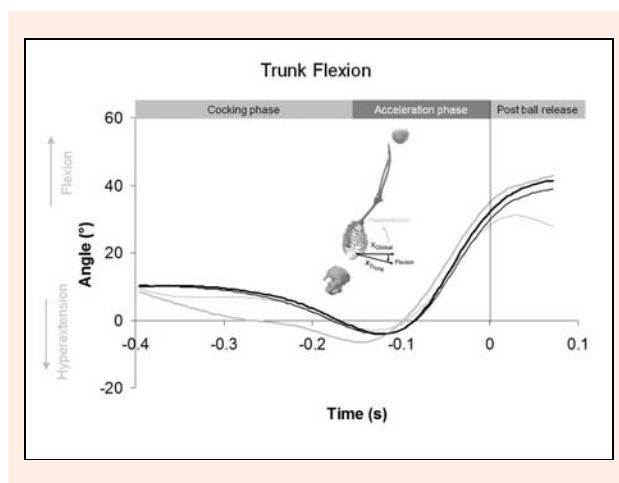


Figure 3. Trunk flexion mean angle curves in the standing throw with (thick black line) and without run-up (thin black line), jump throw (thick grey line), and pivot throw (thin grey line).

Throwing accuracy was determined by the percentage of the throws that missed the target relative to all throws for each participant and the mean radial error (van den Tillaar and Ettema, 2003). Mean radial error was calculated as the distance of the ball target impact point to the center of the target and was measured with Peak Motus 9.0 (Vicon Peak, Oxford, UK) using a digital video camera, operating at 120 Hz.

Statistical analysis

Statistical analysis was conducted via SPSS ver. 16.0 (SPSS Inc., Chicago, IL) software. Means and standard deviations of the variables were calculated for descriptive statistics. A general linear model with repeated measures, analysis of variance and the Bonferroni post-hoc test was used to calculate the statistically relevant differences in performance between the four throwing techniques (within subject factors) as listed in Table 1 (dependent variables). Pearson Product-Moment correlations were used to calculate the influence of kinematic parameters to ball velocity (Table 2). Dependent on correlation results, additional general linear models with repeated measures were calculated to determine the differences in selected kinematic variables between the four throwing techniques (Figure 5A-D). P-values for determination of statistical

differences were adjusted using the Bonferroni correction depending on the number of variables.

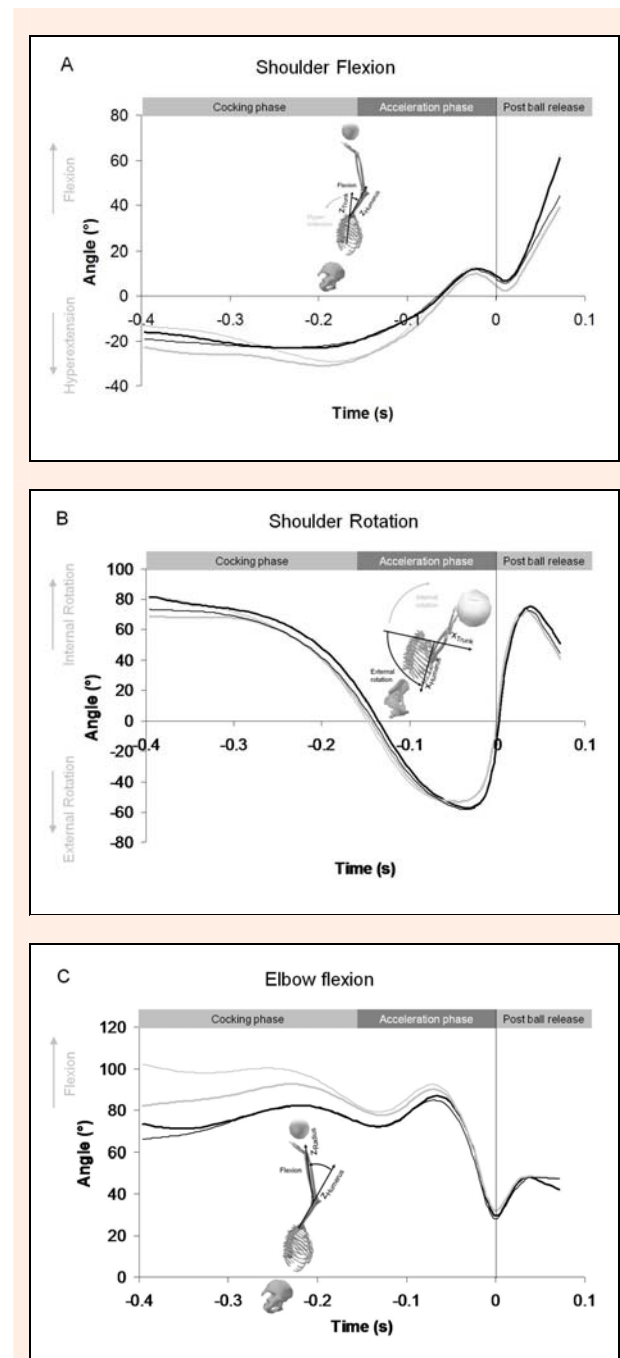


Figure 4. Shoulder flexion (A), shoulder rotation (B) and elbow flexion (C) mean angle curves in the standing throw with (thick black line) and without run-up (thin black line), jump throw (thick grey line), and pivot throw (thin grey line).

Results

Significant differences ($p < 0.001$) in performance were found between the four throwing techniques for the ball velocity but not for the percentage of missed throws and the mean radial error (Table 1).

High and significant ($r > 0.70$, $p < 0.001$) correlations to the ball velocity were found for the maximal

Table 1. Ball velocity, maximal velocity of the center of mass in goal-directed movement and throwing accuracy variables for all throwing techniques. *P*-value for determination of statistical differences for four variables, adjusted using the Bonferroni correction $P < 0.01$. Data are means (\pm SD).

	standing throw without run-up	standing throw with run-up	jump throw	pivot throw	<i>P</i> -value	Effect size
Velocity ($m \cdot s^{-1}$)						
Ball velocity	22.3 (1.2)	23.9 (1.2)	21.9 (1.6)	20.4 (1.2)	< .001 _{a,c,d,e,f}	.97
Maximal velocity center of mass in goal-directed movement	1.5 (.3)	3.0 (.3)	2.6 (.4)	1.6 (.3)	< .001 _{a,b,d,e,f}	.95
Throwing precision						
Missed throws (%)	16 (12)	20 (7)	19 (10)	15 (11)	.44	.21
Mean radial error (m)	.30 (.11)	.30 (.10)	.32 (.07)	.38 (.08)	.21	.51

a: significant difference ($p < 0.05$) between standing throw with and without run-up; b: significant difference ($p < 0.05$) between standing throw and jump throw; c: significant difference ($p < 0.05$) between standing throw and pivot throw; d: significant difference ($p < 0.05$) between standing throw with run-up and jump throw; e: significant difference ($p < 0.05$) between standing throw with run-up and pivot throw; f: significant difference ($p < 0.05$) between jump throw and pivot throw.

pelvis and trunk rotation angular velocity, moderate ($r > 0.50$, $p < 0.001$) correlations were found for the velocity of the center of mass in goal-directed movement ($r = 0.54$, $p < 0.001$), the maximal external pelvis and trunk rotation angle and the timing of the maximal internal trunk rotation angle as well as knee flexion (follow leg) angular velocity and small ($r < 0.50$, $p < 0.001$) correlations were found for the maximal shoulder internal rotation and elbow extension angular velocity, maximal hip flexion and extension angle (lead leg) and timing of the maximal trunk external rotation angle (Table 2).

Based on the results of the Pearson Product-Moment correlations we calculated differences between the four throwing techniques in selected maximal angular velocities and between angles and their timing as shown in Figure 5A-D. Significant differences ($p < 0.002$) between the four different throwing techniques were found in the maximal pelvis ($p < 0.001$, $\eta^2 = 0.91$), trunk ($p < 0.001$, $\eta^2 = 0.90$) and shoulder ($p < 0.003$, $\eta^2 = 0.74$) internal rotation angular velocity and the timing ($p < 0.003$, $\eta^2 = 0.75$) of the maximal trunk internal rotation angular velocity (Figure 5A). Significant differences between the four throwing techniques were also found for the maximal pelvis ($p < 0.001$, $\eta^2 = 0.96$) and trunk ($p < 0.001$, $\eta^2 = 0.89$) external/internal rotation angle as well as the timing of the maximal pelvis external ($p < 0.001$, $\eta^2 = 0.94$) and trunk external/ internal ($p < 0.001$, $\eta^2 = 0.90$) rotation angle (Figure 5B). In the lower body we found significant differences in the maximal hip hyperextension ($p < 0.001$, $\eta^2 = 0.93$) angular velocity of the follow leg as well as the maximal hip flexion ($p < 0.001$, $\eta^2 = 0.96$) angular velocity of the leading leg and their timing ($p < 0.001$, $\eta^2 = 0.84$) as shown in Figure 5C and in the maximal hip flexion ($p < 0.001$, $\eta^2 = 0.84$) and hyperextension ($p <$

0.001 , $\eta^2 = 0.96$) angle as well as the timing of the maximal hip flexion ($p < 0.002$, $\eta^2 = 0.75$) and hyperextension ($p < 0.002$, $\eta^2 = 0.79$) angle of the leading leg as shown in Figure 5D.

Discussion

It was not surprising that there were no significant differences in the throwing accuracy since the participants of our study were elite team-handball players with experience in training (10.8 ± 3.8 yrs) and competition. Players were familiar with all utilized throwing techniques and they were able to hit the target frequently and accurately. In agreement with recent studies in team-handball throwing (Bayios and Boudolos, 1998; Fradet et al., 2004; Goroziaga et al., 2005; Sibila et al., 2003; van den Tillaar and Ettema, 2004; 2007; Wagner and Müller, 2008; Wagner et al., 2010a; 2010b) the participants in our study achieved the greatest ball velocity in the standing throw with run-up (defined as 100% ball velocity), followed by the standing throw without run-up (93%), jump throw (92%) and pivot throw (85%). Bartlett and Best (1998), Bartlett et al. (1996) and Morris et al. (2001) found that in javelin throwing the run-up velocity is an important contributor to javelin velocity and that javelin throwers of different performance level differ in run-up as well as javelin velocity. In javelin throwing, release velocity can be considered as the sum of run-up velocity and velocity generated by the thrower movements (Bartlett and Best, 1988). In the present study we found a correlation between the velocity of the center of mass in goal-directed movement and ball velocity, as well as significant differences in the ball velocity and velocity of the center of mass in goal-directed movement. Therefore, in team-handball,

Table 2. Pearson Product-Moment correlation coefficients and *P*-values between kinematic parameters and ball velocity. *P*-value for determination of statistical differences for 52 variables adjusted using the Bonferroni correction $P < 0.001$.

	Maximal angular vel.	Timing of max. angular vel.	Maximal angle	Timing of max. angle
Hip flexion (lead leg)			$r = .49$, $P < .001$	
Hip extension (lead leg)			$r = .48$, $P < .001$	
Knee flexion (follow leg)		$r = .52$, $P < .001$		
Pelvis external rotation			$r = .64$, $P < .001$	
Pelvis internal rotation	$r = .72$, $P < .001$			
Trunk external rotation			$r = .65$, $P < .001$	$r = -.49$, $P < .001$
Trunk internal rotation	$r = .78$, $P < .001$			$r = .51$, $P < .001$
Shoulder internal rotation	$r = .47$, $P < .001$			
Elbow extension	$r = .47$, $P < .001$			

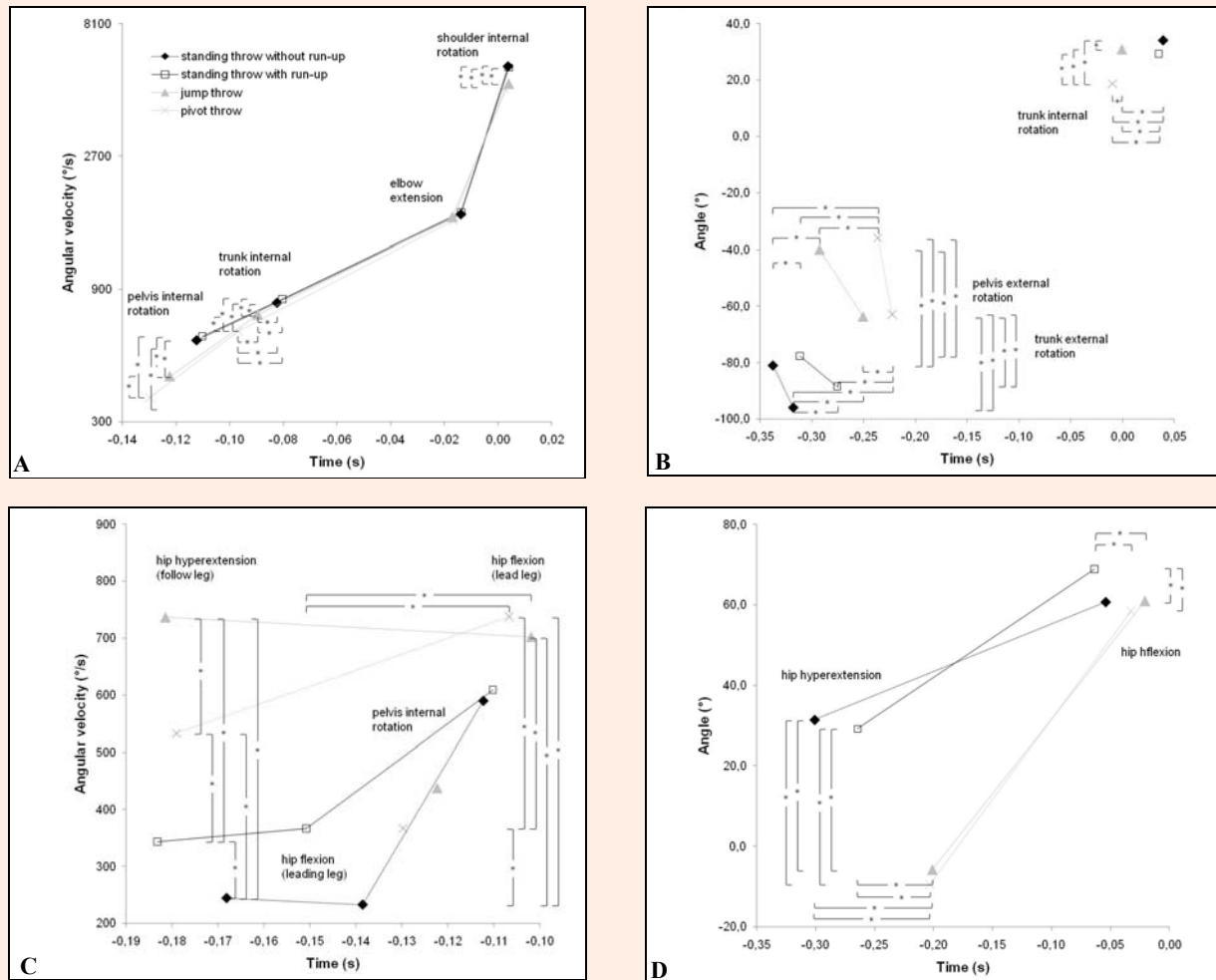


Figure 5. Mean values and significant differences between the four throwing techniques in the maximal pelvis internal rotation, trunk internal rotation, elbow extension and shoulder internal rotation angular velocity and their timing (A), maximal pelvis external, trunk external and trunk internal rotation angle and their timing (B), hip hyperextension (follow leg), hip flexion (lead leg) and pelvis internal rotation angular velocity and their timing (C) and maximal hip hyperextension and flexion angle of the lead leg and their timing (D). *P*-value for determination of statistical differences for 22 variables adjusted using the Bonferroni correction $P < 0.002$.

throwing run-up velocity is an important contributor to the ball velocity.

Differences in the knee flexion/extension and hip flexion/extension angles as shown in Figure 2A-D and 5D could be explained by the influence of jump in the jump and pivot throw compared to the standing throws. Knee and hip of the follow leg were more flexed (Figure 2A and C) and hip of the lead leg were more hyperextended (Figure 2D) when jumping whereas this flexion and extension angles were higher in the jumps were take-off happened on one leg (jump throw) compared to two legs (pivot throw). But how those these influence the ball velocity?

In javelin throwing, Whiting et al. (1991) suggested that the lead leg braces the body, which allows the pelvis, trunk and throwing arm to accelerate over the braced leg and aid in a transfer of momentum through the pelvis and trunk to the throwing arm. Similar results to javelin throwing were also found in the baseball throw (Matsuo et al., 2001; Stodden et al., 2001). As shown in Figure 5A in the team-handball standing throw with run-up that is similar to baseball and javelin throwing (Figure

1B) maximal angular velocity increased in a proximal-to-distal order beginning with the pelvis rotation through the trunk rotation and elbow extension to the shoulder internal rotation. In javelin (Whiting et al., 1991) and baseball (Matsuo et al., 2001) throwing, better throwers exhibit a clear double flexion-extension pattern in the knee angle of the leading leg that was also found in our study (Figure 2B). In combination with a maximal pelvis and trunk external rotation angle of about 80-90° (Figure 3E, F and 5B) participants in our study were able to transfer more energy from the trunk to the throwing arm (Stodden et al., 2001). The importance of the maximal pelvis and trunk rotation angular velocity and the maximal pelvis and trunk external angle in the team-handball throwing movement could be shown by the high correlations (Table 2) to ball velocity. The energy transfer from lower body to the throwing arm could explain the higher maximal pelvis rotation, trunk rotation and shoulder internal rotation angular velocity as well as ball velocity in the standing throw with run-up compared to the jump and pivot throw (Figure 5A). As shown by the throwing sequence in Figure 1A and B and the angles in Figures 2-4, the stand-

ing throw without run-up is similar to the standing throw with run-up. We suggest that the missing run-up in the standing throw without run-up leads to a decrease in the ball velocity (we found a significant correlation between run-up and ball velocity) although the maximal pelvis, trunk and shoulder internal rotation as well as elbow extension angular velocity was not significantly different (Figure 5A). In the jump and pivot throw, the missing floor contact of the lead leg demands a different strategy to rotate the pelvis and enable a transfer of momentum through the trunk to the throwing arm. We observed that in the jump and pivot throw the pelvis internal rotation was assisted by the follow leg hip hyper- and knee extension and lead leg hip flexion. To explain this in detail we calculated the differences in the maximal hip hyperextension (follow leg) and flexion (lead leg) angular velocity and their timing as shown in Figure 5C. We measured significant differences in the maximal angular velocity of the hip hyperextension (follow leg) and hip flexion (lead leg) between the jump/pivot and standing throw. We postulate that the dynamic movements of both legs in different directions (lead leg flexion vs. follow leg extension) induced an additional torque in the pelvis. Therefore, the significant differences in the maximal pelvis internal rotation angular velocity between the jump ($438 \pm 105^\circ/\text{s}$) and pivot throw ($367 \pm 77^\circ/\text{s}$) may be explained by the significant differences in the maximal follow leg hip hyperextension angular velocity (Figure 5C). In team-handball standing (Wagner and Müller, 2008) and jump throw (Wagner et al., 2010a) differences in the ball velocity were due to significant differences in the maximal trunk flexion, rotation and shoulder internal rotation angular velocity. The energy transfer from the pelvis to the shoulder (Figure 5A) suggests that the differences between the four throwing techniques in the maximal pelvis, trunk and shoulder internal rotation angular velocity were due to the differences in the lower extremity movements and the decreased maximal pelvis and trunk external rotation angle. The importance of an energy transfer from the pelvis to the shoulder was also shown in baseball (Matsuo et al., 2001; Stodden et al., 2005) and javelin throwing (Bartlett et al., 1996; Morris et al., 2001; Whiting et al., 1991).

However, the mean angle time series of all participants shown in Figures 2-4 illustrates not only the differences but also the similarities of the four throwing techniques. Because of standing vs. jumping (one vs. two legged take-off) we found differences in the lower body movements (hip and knee flexion/extension) as well as pelvis and trunk external rotation (Figure 5B). In combination with versus without run-up this leads to differences in the maximal upper body angular velocities and the ball velocity. However, a proximal-to-distal sequencing as shown in recent studies in team-handball throwing (van den Tillaar and Ettema, 2009; Wagner et al., 2010a) was used in all four throwing techniques and the angles in the throwing arm, especially in the acceleration phase were quite similar (Figure 3). The participants of our study were able to adapt to different lower body and trunk movement in the four throwing techniques that enabled similar movement of the throwing arm. We found that team-handball players are generally able to adapt to dif-

ferent lower body and trunk movements and similarly also adjust movement of the throwing arm.

Conclusion

In the present study we analyzed performance and kinematics of 14 elite team-handball players in the standing throw with and without run-up, jump, as well as pivot throw and found a significant influence of run-up and pelvis as well as trunk movements to the ball velocity and significant differences in the ball velocity, velocity of the center of mass in goal-directed movement and 15 (maximal angles and angular velocities and their timing) kinematic parameters. Depending on the floor contact (standing vs. jump throws) the elite players of the study used two different strategies (lead leg braces the body vs. opposed leg movements during flight) to accelerate the pelvis and trunk that caused differences in ball velocity. However, the elite team-handball players were able to utilize the throwing arm similarly in all four throwing techniques.

For team-handball coaches and athletes, the results of this study suggest that for team-handball players to increase performance, the players had to learn two different strategies of pelvis and trunk acceleration depending on the floor contact (standing vs. jump throw) and adapt to differences in the lower body and trunk movements that enable similar movements of the throwing arm.

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Key points

- Elite team-handball players achieved the greatest ball velocity in the standing throw with run-up (100%), followed by the standing throw without run-up (93%), jump throw (92%) and pivot throw (85%).
- Depending on the floor contact (standing vs. jump throws) the elite players of the study used two different strategies (lead leg braces the body vs. opposed leg movements during flight) to accelerate the pelvis and trunk that caused differences in ball velocity.
- Elite team-handball players were able to utilize the throwing arm similarly in all four throwing techniques.

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