South African Journal for Research in Sport, Physical Education and Recreation, 2021, 43(1): 125 - 139.
Suid-Afrikaanse Joernaal vir Navorsing in Sport, Liggaamlike Opvoedkunde en Ontspanning, 2021, 43(1): 125 - 139.
ISBN: 0379-9069

KINEMATIC VARIABLES OF ELITE HANDBALL PLAYERS DURING THROWING FROM UPWARD JUMPS

Qais B. YASEEN[1], Irina V. PETRACHEVA[2], Yuri N. KOTOV[2], Rafat S.A. ELTIBI[1]

[1] *Department of Physical Education, An-Najah National University, Nablus, Palestine*

[2] *Russian State University of Physical Education, Sport, Youth and Tourism (SCOLIPE), Moscow, Russia*

ABSTRACT

This study aimed to analyse kinematic variables of motor action in throwing from upward jumps by first- and second-line players in an elite handball team. Three-dimensional kinematic variables were analysed using the Statokin 3D Video Analysis system. The study sample (n=15) consisted of eight second-line players. The results showed statistically significant differences between players of the second and first-line in the length of the last stride (η^2=0.87, p<0.001), horizontal velocity on the Y-axis (η^2=0.51, p=0.003), average take-off velocity (η^2=0.62, p=0.001), maximal horizontal and vertical velocities (Y and Z-axes) of the knee joint of the swinging leg (η^2=0.53, p=0.002; η^2=0.40, p=0.016), maximal angular velocities of the hip and knee joints of the take-off leg (η^2=0.38, p=0.023; η^2=0.23, p=0.050), angular velocity of the knee joint of the swinging leg (η^2 = 0.61, p < 0.001), maximal extension angle of the elbow during backswing (η^2=0.41, p=0.042), and average speed at which the ball was released (η^2=0.71, p<0.001). The kinematic variables of the motor action of the body joints differed between players from the second- and first-line during throwing from upward jumps.

Keywords: 3D-kinematics; Ball release speed; Jump throw; Handball.

INTRODUCTION

Team handball is an important Olympic sport that is played at a professional level in international competitions. In team handball competitions, scoring goals is of utmost importance (Wagner *et al*., 2010). To maximise the number of goals scored during a competition, handball players are required to optimise the accuracy and velocity of their throws, especially when players throw from backcourt position (more than 8m from the goal). Depending on their position in the game and movements of the defensive players, team handball players use different throwing techniques (Wagner *et al*., 2011).

Recently, biomechanics in handball has received considerable attention. Researchers in the field have analysed different throwing techniques including standing throws, throwing from the spot with cross-over step and throwing from upward jumps (Jöris *et al*., 1985; Sibila *et al*., 2003; Fradet *et al*., 2004; Van den Tillaar & Ettema, 2004; Gorostiaga, 2005; Pori *et al*., 2005; Van den Tillaar & Ettema, 2007; Wagner & Müller, 2008; Wagner *et al*., 2011). These researchers also determined the speed of the released ball as an important determinant of the efficacy of the throws. Among all throwing techniques, throwing from an upward jump is the most frequently used technique in team handball (Wagner *et al*., 2008). It has been estimated that 73%-75% of all throws during handball competitions are throws from an upward jump (Wagner *et al*., 2008).

Analysing the throwing technique is of special importance because it can provide essential information on the efficacy of throws. Studying kinematic variables of throws has many applications in the field of biomechanics. Applications include obtaining more information on these variables, allowing coaches and players to find ways to optimise the efficacy of throws and designing individualised training sessions to improve performance of elite handball players (Wagner *et al.*, 2010). Additionally, quantitative analysis of the kinematic variables and motor actions of the musculoskeletal system might permit finding ways to optimise transferring momentum from the lower parts of the body to the upper parts and passing the kinetic energy to the released ball (Shalmanov *et al*., 2013).

Kinematic analysis has emerged as an essential tool in understanding the different elements of the movements and behaviour of handball players during throws. Therefore, kinematic analysis of throwing from an upward jump could provide accurate and in-depth knowledge and understanding of the different phases of the throw including the different motor actions of the body joints. Little is known on the kinematic differences between elite handball players who play in the first (front) and second (back) lines during a throw from an upward jump.

PURPOSE OF STUDY

The present study was conducted within the scope of broadening understanding of biomechanics, particularly within the context of handball. This study was conducted to assess and compare the kinematic variables of elite handball players who played in the first- and second-line during throwing from upward jumps. Findings of the study could provide new insights into the kinematics of throwing from upward jumps in handball. These findings might inform coaches and handball players on the different ways to optimise throwing from upward jumps during competitions.

METHODOLOGY

Participants

In this study, the kinematic variables of handball players (n=15) who played in an elite handball team were analysed. The best players in the elite team were selected. Players were included if they met the following inclusion criteria: (a) 20 years of age or older; (b) of more than 180cm in height; (c) participated in training sessions and competitions; (d) had experience of 8 and more years; (e) had no injuries limiting their participation in competitions; and (f) could throw the ball at a velocity of more than 22m/s.

Of the 15 players selected, seven played in the first attack line (height=1.83±0.06m; weight=80.4±5.5kg; age=23.0±0.53 years) and eight played in the second attack line (height=1.95±0.11m; weight 83.1±4.2kg; age=24.0±0.52 years). All players who took part in this study were in good health and did not report any injuries limiting their participation in competitions as determined by the medical centre.

Ethical clearance

The present study received ethical approval from the Institutional Review Board (IRB) of An-Najah National University on 25th of February 2020. The study "Kinematic mechanism of elite handball players during throwing from upward jump" was reviewed and achieved under the protocol # OTH 2/20/19.

Measuring instruments

Electronic video analysis

To study and analyse the kinematic variables, throws from upward jumps were captured using an electronic video analysis system (Statokin 3D Video Analysis, Scientific Medical Company, "STATOKIN", Moscow, Russia). The electronic video analysis system was designed to study human movements by computerised analysis of recorded videos. The system used for analysis in this study could provide the following: (a) recording video frames; (b) capturing motion and incidents in three dimensions; (c) angular measures of human movements; and (d) kinematic measures. Two video cameras (Basler A601f, German) with a frequency of 50fps were used to capture the movements of the handball players. Light equipment, tripods for cameras, and 18 reflective markers were utilised. Movements of the players were registered on the X, Y, Z axes as shown in Figure 1.

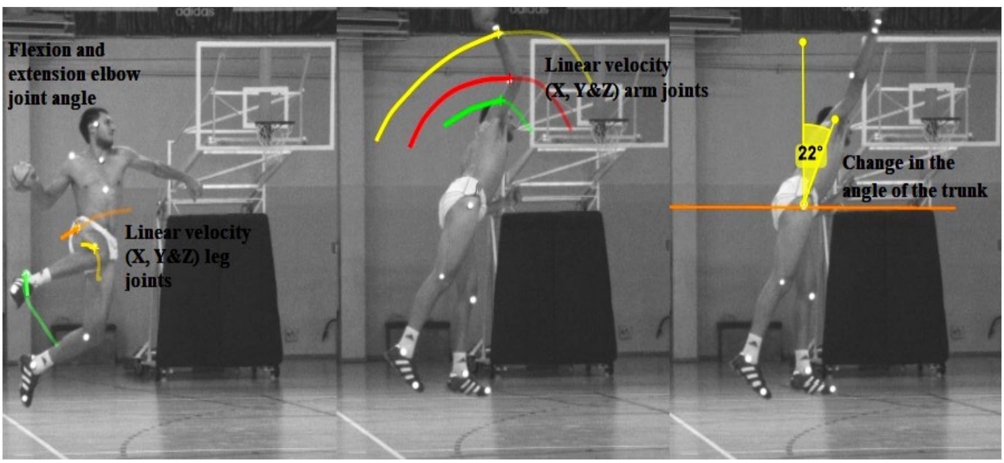


Figure 1. **SOME KINEMATIC VARIABLES USED IN ANALYSIS OF THROWING FROM AN UPWARD JUMP**

During video filming, the angle between the camera and the players was fixed at 90°. Retroreflective markers were fixed on the body parts of the players. Anatomical landmarks were used to place markers on both sides of the body of each player. Markers were placed on the hands, wrists, elbows, shoulders, hips, knees, ankles, first metatarsal head, and temples of the head. Markers were also placed on the ball.

Measurement of kinematic variables

Individual kinematic variables like linear and/or angular velocities and angles of motion (motor actions) of each player were measured. Measurements were taken to accurately visualise, describe, analyse, evaluate and compared the different parts of the throw between players from the first- and second-line. The maximal speed of the released ball (Vt RELEASE) was measured after the ball was released from the hand of the player. The length of the last step (the distance between the back instep and the front heel) was also measured. Measurements were taken as previously described by Wagner *et al.* (2010).

The methods used were informed by those used in previous kinematic studies in handball (Sibila *et al.,* 2003; Fradet *et al.,* 2004; Van den Tillaar & Ettema, 2007); bowling (Ranson *et al.,* 2008) and volleyball (Tilp *et al*., 2008; Wagner *et al*., 2009). The orientations were identified using three orthogonal axes (X-axis, Y-axis and Z-axis). Joint angles were calculated using a method previously reported by Wagner *et al.* (2009) and Wagner *et al*. (2010). Three-dimensional joint angles were calculated using the angle between the longitudinal axes and between two adjacent segments. Joint flexion angles (elbow and knee) were determined by the longitudinal axis between the proximal and distal segments. The change in the angle of the torso was determined from the beginning of the acceleration phase until the ball was released. The maximal linear velocity for the arm joints during the acceleration phase and the ball release speed and the linear velocities of weighted joints during elevation and acceleration phases (thrusting the leg back) were measured (Figure 1) were measured.

Procedures

The players were given a 20-minutes handball session to warm-up and reduce the risk of injuries. Players were then instructed to make throws from upward jumps from a horizontal distance of 9m from the goal. It is noteworthy that in international handball competitions, players often make throws with an upward jump from a horizontal distance of 8-12m from the goal box. In this study, the players were supposed to release the ball in a window of 0.5x0.5m^2 aiming at maximal accuracy and speed almost at eye level (height 1.75m). Each player was instructed to make 5 throws from upward jumps. Of the five throws, three were selected for the kinematic analysis (Wagner *et al.,* 2008).

In handball games, throwing from an upward jump can be divided into the following successive phases, namely approaching phase, take-off phase, swing up phase, acceleration phase, ball release phase and landing phase (Sibila *et al*., 2003; Wagner *et al*., 2008). The approaching phase was considered from the last running step of the player, when the swinging leg (right) left the ground and the take-off leg remained in contact with the ground. The take-off phase was considered as the time interval from the beginning to the end of contact between the take-off leg and the ground. The swing-up phase was considered from the moment the foot of the take-off leg left the ground to the moment the player reached the maximal flying phase and the angle of the elbow joint was fully extended. The acceleration phase was considered from the moment the angle of the elbow joint reached the maximal range until the moment the ball was released (Wagner *et al.,* 2008). The landing phase was considered from the moment the ball was released until the elevated foot touched the ground.

Statistical analysis

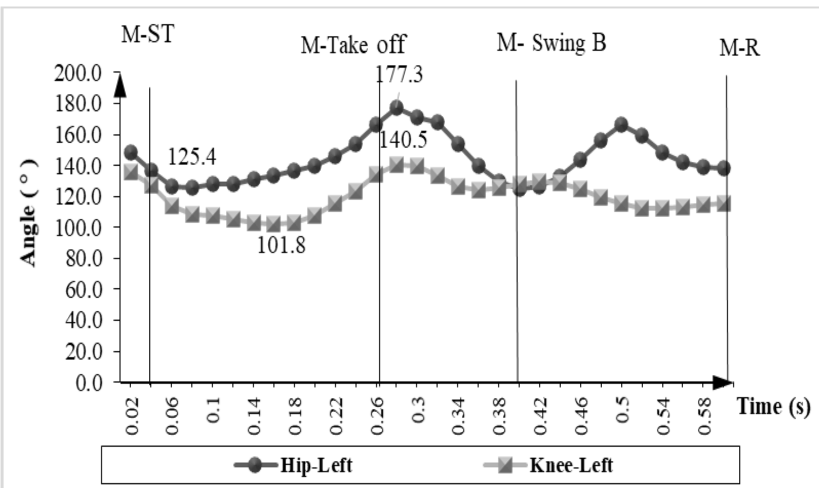
The data collected in this study were analysed using Statistical Package for the Social Sciences (SPSS v.22.0, SPSS Inc., Chicago, IL, USA). The data were tested for normality of distribution by Kolmogorov–Smirnov test. Because the data were normally distributed, descriptive statistics like the average (mean), maximal value, minimal value, and standard deviation (SD) were used to describe the variables. One-way analysis of variance (ANOVA) and eta squared (η^2) for effect size were used to assess differences between groups.

RESULTS

The kinematic variables of elite handball players were measured and analysed to understand mechanisms of the motor action during throwing from upward jumps. The analysis included mechanisms, like flexion and extension of the body joints, actions of the swinging leg, movement of arms (kinetic chain) and joints of the throwing arm during acceleration. The kinematic variables during throwing from upward jumps were compared between the first and second attack lines of the elite handball players.

Mechanisms of flexion and extension of joints

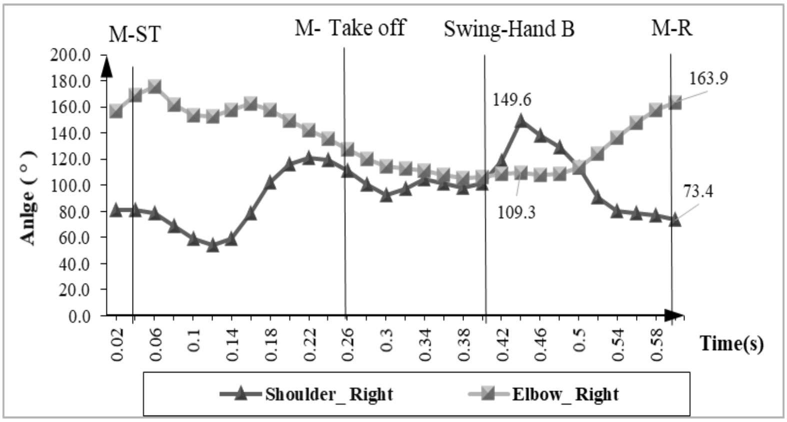
Figure 2a shows the angular changes in leg joints (the take-off leg) while throwing from upward jumps. During this action, players started running in order to increase their speed in the approaching phase.



M-ST=Moment of placing the take-off leg on the ground M-Take off=Moment of take-off
M-Swing B=Moment swing back M-R=Moment of releasing the ball

Figure 2a. **ANGULAR CHANGE IN CENTRED LEG (UPLIFTED) DURING AIMING SKILL OF UPWARD JUMP**

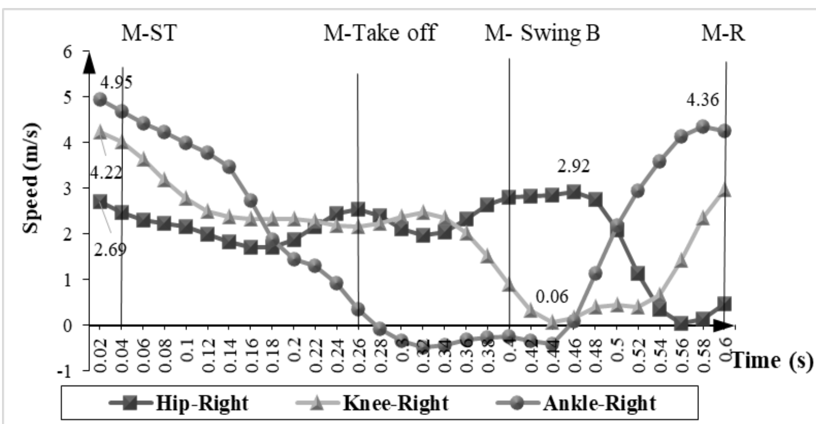
At the end of the approaching phase and after players had placed their right foot on the ground, the braking phase began by slowing the velocity of the final step, the take-off leg (left foot) was put on the floor and the flexing movement began. There was a change in the mechanism complex operation for the hip and knee joints. The hip joint achieved a maximal flexion (125.4°). The knee joint achieved maximal flexion (101.8°) during the braking phase. By the end of this phase, the knee joint extension reached 140.5° when the foot left the ground. The hip joint extension reached 177.3° (Figure 2a).



M-ST=Moment of placing the take-off leg on the ground M-Take off=Moment of take-off
M-Swing-Hand B=Moment swing back M-R=Moment of releasing the ball

Figure 2b. **ANGULAR CHANGE IN ARM JOINTS DURING THE AIMING SKILL OF UPWARD JUMP**

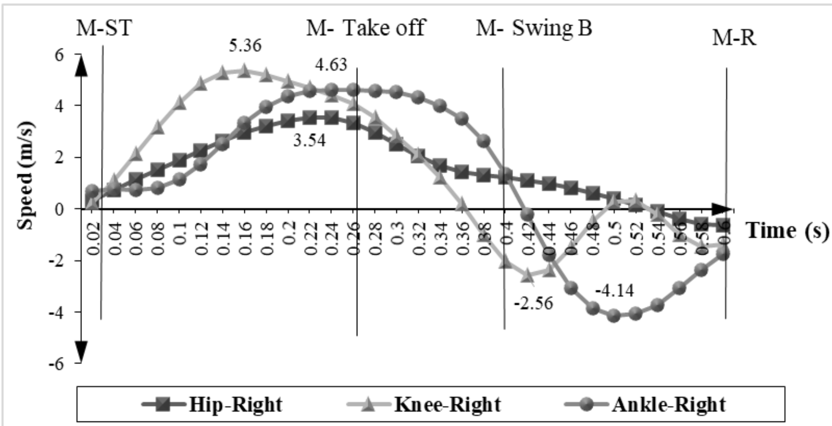
Mechanisms of flexion and extension of the arm swing are shown in Figure 2b. During take-off and flying phases, players rotated their trunks and turned their arms to the back while they prepared for the acceleration and throwing phases. The maximal shoulder joint extension (shoulder abduction) of the throwing arm achieved 149.6° and the abduction elbow joint achieved 109.3°. The angle of the elbow adduction joint increased to 163.9° while releasing the ball. The angle of the shoulder joint achieved 73.4°.



M-ST=Moment of placing the take-off leg on the ground M-Take off=Moment of take-off
M-Swing B=Moment swing back M-R=Moment of releasing the ball Swing hand B=Swing hand back

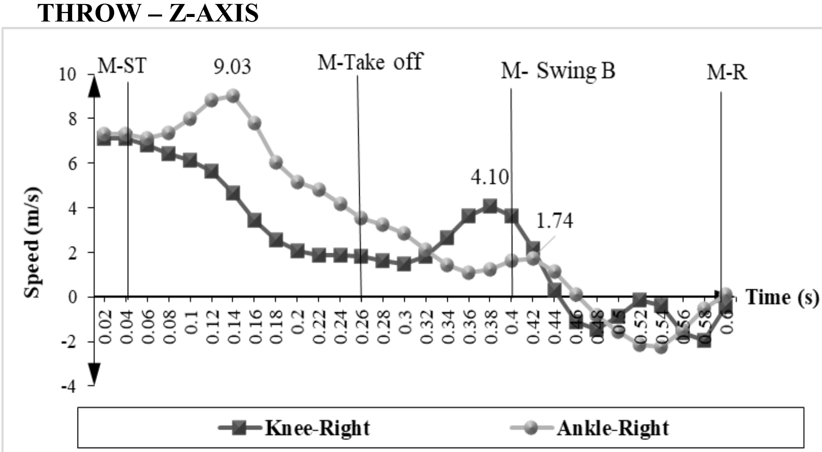
Figure 3a. **LINEAR VELOCITY OF LEG SWING DURING UPWARD JUMP THROW – Y-AXIS**

Mechanisms of leg swinging are shown as changes in linear velocities of the leg swing joints on the X-, Y- and Z-axes (Figure 3a, 3b, 3c). During swinging of the right leg and after placing the take-off leg on the ground, the maximal horizontal velocities on the Y-axis were 4.22m/s, 4.95m/s and 2.69m/s for the knee, ankle, and hip joints, respectively. The maximal vertical velocities on the Z-axis during take-off were 3.54m/s, 5.36m/s, and 4.63m/s for the hip, knee, and ankle joints, respectively. When the player took off and achieved the maximal height, the leg swinging was in the opposite direction of the throwing arm.



M-ST=Moment of placing the take-off leg on the ground M-Take off=Moment of take-off
M-Swing B=Moment swing back M-R=Moment of releasing the ball Swing hand B=Swing hand back

Figure 3b. **LINEAR VELOCITY OF LEG SWING DURING UPWARD JUMP THROW – Z-AXIS**



M-ST=Moment of placing the take-off leg on the ground M-Take off=Moment of take-off
M-Swing B=Moment swing back M-R=Moment of releasing the ball Swing hand B=Swing hand back

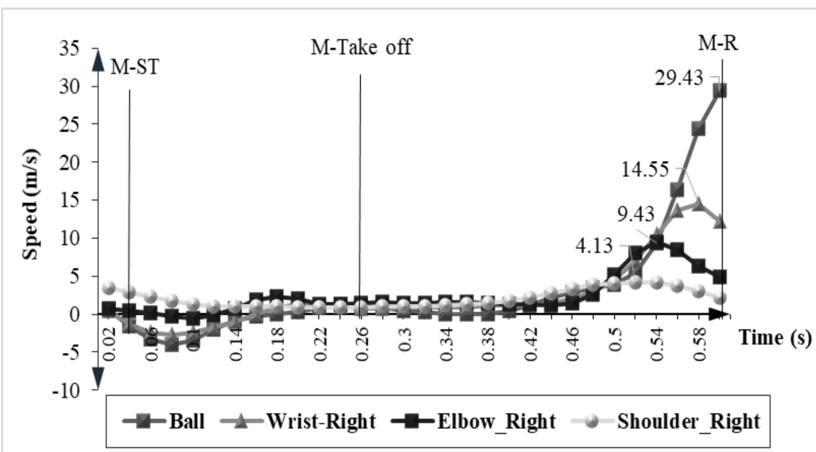
Figure 3c. **LINEAR VELOCITY OF LEG SWING DURING UPWARD JUMP THROW – X-AXIS**

During the acceleration phase to throw the ball, the horizontal velocity of the hip joint on the Y-axis increased to 2.92m/s and that of ankle joint decreased to 0.06m/s.

The maximal vertical velocity of the knee joint on the Z-axis during the leg swinging was 2.56 m/s and that of the ankle joint was 4.14m/s. When the ball was released, the horizontal velocity on the Y-axis increased to 4.36m/s for the ankle joint and 2.97m/s for the knee joint. However, the velocity of the hip joint was 0m/s, which indicated that the hip joint did not move when the ball was released. On the X-axis, the maximal lateral velocity of the ankle joint during the take-off phase was 9.03m/s which then decreased to 1.1m/s. During the acceleration phase and downward and backward swing of the leg, the maximal linear velocity on the lateral axis for the knee joint was 4.1m/s and that of the ankle joint was 1.74m/s (Figure 3c).

Mechanism of arm "whip" during acceleration

Changes in velocities of arm joints (shoulder, elbow and wrist) and velocity of the ball on the Y, Z and X axes are shown in Figure 3d. From the beginning of the acceleration phase until the ball was released, changes in coordination of the arm joints on the Y-axis were 0.52m, 0.87m, and 1.22m for the shoulder, elbow and wrist joints, respectively. The maximal horizontal velocities on the Y-axis were 4.13 m/s, 9.43 m/s, 14.55 m/s for the shoulder, elbow, and wrist joints, respectively. The maximal velocity of the ball released was 29.43m/s. Movements and increased velocities of the proximal to distal arm joints on the Y-axis resembled a whip. The vertical displacements of the joints on the Z-axis were calculated from the beginning of the acceleration phase until the ball was released. The vertical displacements were 0.13m, 0.55m and 0.69m for the shoulder, elbow and wrist joints, respectively. This indicated that movements of the arm on the X-axis were complex and the maximal linear velocity of the shoulder joint during the acceleration phase was 4.66m/s and that of the elbow joint was 3.36m/s.



M-ST=Moment of placing the take-off leg on the ground M-Take off=Moment of take-off
M-Swing B=Moment swing back M-R=Moment of releasing the ball Swing hand B=Swing hand back

Figure 3d. **LINEAR VELOCITY OF ARM JOINTS DURING UPWARD JUMP THROW – Y-AXIS**

In this analysis, there was a statistically significant difference in the length of the last stride between players of the second- and first-line (η^2 =0.87, p<0.001). Also, there was a significant high correlation between the length of the stride and the velocity of the ball released (r=0.843; p<0.001). The horizontal velocity on the Y-axis (η^2=0.51, p=0.003) and the average take-off velocity (η^2=0.62, p=0.001) differed significantly between players of the second- and first-line as shown in Table 1.

Table 1. **LINEAR KINEMATIC VARIABLES IN APPROACHING AND TAKE-OFF PHASES DURING HIGH JUMP THROW**

Kinematic variable	Position of player	n	Mean±SD	Min–Max	p	Effect size
Length of the last stride (m)	Second First	8 7	1.18±0.06 0.90±0.04	1.10–1.31 0.83–0.95	<0.001	0.87
Horizontal velocity of centre of body centre in last stride (m/s)	Second First	8 7	3.09±0.39 2.60±0.23	2.60–3.79 2.24–2.96	0.003	0.51
Average take-off of players from moment leaving ground until reaching maximal height (m)	Second First	8 7	0.53±0.04 0.44±0.08	0.48–0.59 0.34–0.52	0.001	0.62

Table 2. **KINEMATIC VARIABLES OF BOTH LEGS DURING TAKE-OFF AND FLY**

Kinematic variable	Position of player	n	Mean±SD	Min–Max	p	Effect size
Maximum horizontal velocity of knee joint of swing leg (right) when performing take-off (m/s)	Second First	8 7	4.32±0.49 3.78±0.39	3.42–4.79 3.15–4.30	0.002	0.53
Maximal vertical velocity of the knee joint of swing leg (right) when performing take-off (m/s)	Second First	8 7	5.27±0.03 4.31±0.31	4.10–6.93 3.75–4.74	0.016	0.40
Maximal angular velocity of hip joint of take-off leg (left) during take-off (°/s)	Second First	8 7	317.40±67.6 230.30±59.5	229.10443.40 180.40–299.10	0.023	0.38
Maximal angular velocity of knee joint of take-off leg (left) during take-off (°/s)	Second First	8 7	300.20±61.8 243.50±65.8	234.90–405.10 143.20—351.80	0.050	0.23
Maximal angular velocity of knee joint of swing leg (right) during backswing (°/s)	Second First	8 7	916.70±275.5 546.60±178.7	641.70–1504.00 229.10–743.70	<0.001	0.61

Similarly, there was a statistically significant difference in the maximal horizontal and vertical velocities (Y and Z-axes) of the knee joint of the swinging leg between second- and first-line players (η^2=0.53, p=0.002; η^2=0.40, p=0.016, respectively). Again, there was a statistically significant difference in the maximal angular velocities of the hip and knee joints of the take-off leg during the take-off (η^2=0.38, p=0.023; η^2=0.23, p=0.050). The kinematic variables of the swinging leg during the take-off phase are shown in Table 2. The angular velocity of the knee joint of the swinging leg during backswing differed significantly between second- and first-line players (η^2=0.61, p<0.001).

The angular kinematics during brake and take-off phases can influence the speed of the released ball. In this study, the minimal take-off leg angles from the brake to take-off of the hip and knee joints for the second-line players were lower than those of the first-line players (131.4° and 144.8° vs. 143.1° and 152.5° respectively). The kinematic variables of the second- and first-line players were significantly different (η^2=0.32, p=0.032; η^2=0.36, p=0.019). Similarly, the maximal extension angle of the elbow during backswing was also significantly different between first- and second-line players (η^2=0.41, p=0.042).

The angle of trunk flexion, from the acceleration of throwing arm until the moment the ball was released, explained effective trunk movement. The average change in the trunk flexion of the first-line players was 13.7°, while that of the second-line players was 16.87°, as shown in Table 3.

***Table 3*. ANGULAR KINEMATIC VARIABLES WHILE THROWING WITH AN UPWARD JUMP**

Kinematic variable	Position of player	n	Mean±SD	Min–Max	p	Effect size
Minimal angle of the knee joint of the take-off leg during the take-off phase (°)	Second	8	144.8±4.49	135.7–149.9	0.019	0.36
	First	7	152.5±5.61	145.2–162.3		
Minimal angle of the hip joint of the take-off leg during the take-off phase (°)	Second	8	131.4±6.50	117.3–137.8	0.032	0.32
	First	7	143.1±9.35	131.4–154.4		
Maximal extension angle of elbow joint of the right hand during backswing (°)	Second	8	109.8±10.53	100.0–127.0	0.042	0.41
	First	7	102.0±7.53	90.0–110.0		
Change in the angle of the trunk during the ball release (acceleration) (°)	Second	8	16.9±2.20	15.0–20.0	0.049	0.35
	First	7	13.7±0.90	12.0–16.0		

During the acceleration phase, the speed of the released ball and the maximal velocity of the throwing arm joints of the second-line players were higher than those of the first-line players (Table 4). The average speed at which the ball was released by second-line players was 24m/s and the maximal speed in the best attempt was 25.41m/s. However, the average speed at which the ball was released by first-line players was 21.7m/s and the maximal speed in the best attempt was 25.41m/s. There was a statistically significant difference in the average speed at which the ball was released by the second- and first-line players (η^2=0.71, p<0.001) (Table 4).

Table 4. **MAXIMAL VALUES FOR HORIZONTAL KINEMATIC VARIABLES OF ARM JOINTS (RIGHT) IN ACCELERATION PHASE AND BALL RELEASE WHILE THROWING WITH AN UPWARD JUMP**

Kinematic variable	Position of player	n	Mean±SD	Min–Max	p	Effect size
Maximal velocity of released ball (m/s)	Second	8	24.00±0.64	23.44–25.41	<0.001	0.71
	First	7	21.70±1.55	19.38–23.33		
Maximal horizontal velocity of wrist joint (m/s)	Second	8	13.59±0.43	13.00–14.16	0.001	0.55
	First	7	12.22±1.01	10.72–13.21		
Maximal horizontal velocity of elbow joint (m/s)	Second	8	10.18±0.47	9.52–10.98	0.098	0.22
	First	7	9.82±0.73	8.65–10.51		
Maximal horizontal velocity of shoulder (m/s)	Second	8	4.42±0.29	4.00–4.89	0.011	0.51
	First	7	4.27±0.38	3.86–4.75		

The average maximal velocity on the Y-axis for the second-line players were 13.59m/s, 10.18m/s, and 4.42m/s for the wrist, elbow, and shoulder joints, respectively. However, average maximal velocity on the Y-axis for the first-line players were 12.22m/s, 9.82m/s, and 4.27m/s for the wrist, elbow, and shoulder joints, respectively. The maximal velocity of the wrist and shoulder joints on the Y-axis for the second- and first-line players differed significantly (η^2= 0.55, p=0.001; η^2=0.51, p=0.011). However, there was no significant difference in the maximal velocity of the elbow joints between the second- and first-line players (η^2= 0.22, p=0.098).

DISCUSSION

During the take-off phase, motor mechanisms absorbed the horizontal velocity of the body and transformed it into vertical velocity through flexion and extension. As the players pushed the ground with maximal force, the angular velocities of the knee and hip joints increased. Probably, these actions allowed the body of the player to rise to the maximal possible height and helped transfer momentum through the joints from the lower to the upper parts of the body as shown in Figure 2a.

In this study, the length of the last stride for the second-line players was significantly longer than that of the first-line players (Table 1). Findings of this study demonstrate the importance of the length of stride in performing throws from upward jumps in handball. In general, findings of this study were consistent with those reported by Ohnjec *et al*. (2010) in which the lengths of the strides were 1.25m, 1.28m, and 1.37m. It has been argued that the length of the stride can help increase the speed of the ball while throwing from upward jumps.

During the approaching phase, the speed of the player was measured by tracking the velocity of the centre of the body during the last stride. Findings of this study suggested that it was important to increase the horizontal velocity in the last step. It is thought that increasing the horizontal velocity might help the player easily surpass defensive players of the other team. The average velocities during the last stride on the Y-axis for the second- and first-line players were lower than those reported in the study of Sibila *et al.* (2003). However, the average velocity of the centre of the body during the last stride was 4.51m/s.

The linear velocity is thought to be important in reducing the take-off and throwing time. In this study, the average take-off for the second-line players was higher than that of the first-line players. During throwing from upward jumps, take-off and flying are important determinants of the effectiveness of the throw as they allow the player to release the ball over the defensive players of the other team. They also allow the players to view the movements of the goalkeeper.

The leg swinging mechanism is thought to play a key role in converting the horizontal velocity to vertical velocity. When the swinging leg moved forward and sideways while the player placed the take-off leg on the ground. This could be seen by the increasing horizontal and lateral velocities on the motion axes. In this case, the velocities of the knee and ankle joints increased in the vertical direction to help raise the body and prepare for the downward and backward leg swinging. When the body reached the maximal height, this might have helped transfer momentum from the lower parts of the body to the upper parts through the joints. This motor mechanism is known as pendulum movement. In this study, the increased velocity in the reverse direction of the flying body could be attributed to the pendulum movement (Figure 3).

Findings of this study indicated a complex movement of the swinging leg. This could be important in transferring the momentum to the upper parts of the body. Analysing changes in the velocity of the arm joints showed that when the player was ready to throw the ball, the elbow joint was in the maximal extension and the velocity of the arm joints increased from the proximal to the distal joint (shoulder to elbow to wrist). In this motor mechanism, motion transferred from the lower parts of the body to the upper parts until the player passed the kinetic energy to the released ball in successive motions is known as the whip mechanism. Findings of this study were consistent with those previously reported in many studies (Sibila *et al.,* 2003; Ohnjec *et al.,* 2010; Yotov & Arakchiyski 2012).

During the take-off phase, the average maximal horizontal and vertical velocities of the knee joint of the swinging leg of the second-line players were 4.32m/s and 5.27m/s. However, these velocities for the first-line players were 3.78m/s and 4.31m/s. The leg swinging is thought to play a key role while performing throws from upward jumps because it can increase the horizontal and vertical velocities during the take-off phase. Increasing these velocities can help players raise their bodies to the maximal height possible.

Findings of this study were different from those reported by Kotov (2009) on handball players of different levels. The average maximal horizontal and vertical velocities of the knee joint of the swinging leg for second-line elite women were 4.10m/s and 3.81m/s. However, these velocities were 3.07m/s and 2.77m/s for first-line elite women. The kinematic variables of the leg swinging were higher than those reported in the study of Kotov.

During the acceleration phase, the maximal angular velocity of the leg swinging was higher for the second-line players compared to the first-line players. This might be explained by the positioning technique of the second-line players in the game. Findings of this study showed that those players could swing their legs to a higher degree, which probably helped them transfer momentum from the lower parts to the upper parts of the body through the joints (Table 2).

In this study, differences in angular kinematics of the hip and knee joints might be explained by differences in roles played in the field and differences in the ways of take-off. Players in the first line needed less time to take-off and enter the area of 6m. Therefore, players did not need to completely bend their joints of the take-off leg to jump and throw (Table 3). The width of the arms swinging was proportional to the extension of the elbow. During preparation phase, the angle of extension of the second-line players was 109.8°, whereas, that of the first-line players was 102°. Differences in the angle of the elbow joint could indicate that increasing the extension might have helped the players to prepare for the acceleration phase and throwing the ball. This could have also provided a wider range of motion and longer period of the throwing phase (Table 3).

The second-line players had greater capabilities with regard to the length of the back arm swinging and in increasing the linear velocity of the arm joint. Probably, this could explain the higher ball speed released by the second-line players. Because there were no differences in the speed of the elbow joint, more investigations are still needed to better understand the complexity of elbow joint rotation, flexion and extension (Table 4).

Differences in the speed of the ball released by the second- and first-line players were obvious in this study. Findings of this study were consistent with those reported in many previous studies (Gorostiaga *et al*., 2005; Van den Tillaar & Ettema, 2006; Wagner & Müller, 2008). The speed of the released ball is an important determinant of performance in team handball. The speed of the ball released by the second-line players in this study were comparable to those previously reported by Sibila *et al.* (2003) for Slovenian elite team-handball players (24.1±1.3m/s) and Pori *et al.* (2005) for Slovenian National Handball Team players (24.0±1.4m/s). This indicated that the elite players who took part in this study were at comparable level with those of international handball teams.

PRACTICAL APPLICATION

In the present study, kinematic variables of elite handball players who played at different positions were analysed. The findings reported significant differences between players in the first- and second-line when performing upward jump throws. Findings of this study could be important for coaches and handball players. To improve performance of elite team handball players in upward jump throws, it could be important to consider the following points.

First, the length of the step should be more than 1m. Second, designing training programmes for first-line players might include using weights to increase angular velocity of the take-off leg and throwing arm and rubber rope to improve the leg swinging and motor mechanisms of the throwing arm (flexion, extension and rotation). Third, trainers might focus on improving the angle of trunk flexion to increase the effectiveness of throws. Fourth, trainers might attempt to improve the motor mechanisms of the joints of the throwing arm from the acceleration phase until the release of the ball. Finally, future studies might focus on analysing the motor mechanisms of the elbow joint.

CONCLUSION

Analysis of kinematic variables enable researchers to identify the most important variables affecting motor mechanism during throwing from upward jumps. Additionally, understanding these variables could be helpful in improving techniques and motion of different parts of the body during throws from upward jumps. Velocity of the joints of the throwing arm and transfer of kinetic energy were important determinants of the speed of the released ball. The vertical velocity of the leg swinging played a major role in increasing the ability of the player to take-off and fly for a longer period of time. Improving movement of the trunk during the acceleration phase could increase the effectiveness of the throws from upward jumps. Further investigations are still needed to better understand the complexity of elbow joint rotation, flexion and extension.

REFERENCES

FRADET, L.; BOTCAZOU, M.; DUROCHER, C.; CRETUAL, A.; MULTON, F.; PRIOUX, J. & DELAMARCHE, P. (2004). Do handball throws always exhibit a proximal-to-distal segment sequence? *Journal of Sport Science*, 22(5): 439-447.

GOROSTIAGA, E.M.; GRANADOS, C.; IBANEZ, J. & IZQUIERDO, M. (2005). Differences in physical fitness and throwing velocity among elite and amateur male handball players. *International Journal of Sports Medicine,* 26(3): 225-232.

JÖRIS, H.J.; EDWARDS VAN MUYEN, A.J..; VAN INGEN SCHENAU, G.J. & KEMPER, H.C.G. (1985). Force, velocity and energy flow during the overarm throw in female handball players. *Journal of Biomechanics*, 18(6): 409-414.

KOTOV, Y.N. (2009). The control effectiveness of the throwing technique in the jump shot of handball players of different qualifications. Unpublished doctoral dissertation. Moscow, Russia: Russian State University of Physical Education, Sport, Youth and Tourism, Department of Physical Education.

OHNJEC, K.; ANTEKOLOVI, L. & GRUI, I. (2010). Comparison of kinematic parameters of a jump shot performance by female handball players of different ages. *Acta Kinesiologica*, 4(2): 33-40.

PORI, P.; BON, M. & SIBILA, M. (2005). Jump shot performance in team handball: A kinematic model evaluated based on expert modelling. *Kinesiology*, 37(1): 40-49.

RANSON, C.A.; BURNETT, A.F.; KING, A.; PATEL, N. & O´SULLIVAN, P.B. (2008). The relationship between bowling action classification and three-dimensional lower trunk motion in fast bowlers in cricket. *Journal of Sports Sciences*, 26(3): 267-276.

SHALMANOV, A.A.; LANKA, Y.E. & MEDVEDEV, V.G. (2013). Methodology for the study and evaluation of technical skills. *Journal Science in Olympic Sports,* 3: 65-72.

SIBILA, M.; PORI, P. & BON, M. (2003). Basic kinematic differences between two types of jump shot techniques in handball. *Acta Universitatis Palackianae Olomucensis. Gymnica*, (trans.: *Applications of Mathematics Palacky University. Gymnastics*), 33(1): 19-26.

TILP, M.; WAGNER, H. & MÜLLER, E. (2008). Differences in 3D kinematics between volleyball and beach volleyball spike movements. *Sports Biomechanics*, 7(3): 386-397.

VAN DEN TILLAAR, R. & ETTEMA, G. (2004). A force-velocity relationship and coordination patterns in overarm throwing. *Journal of Sports Science and Medicine*, 3(4): 211-219.

VAN DEN TILLAAR, R. & ETTEMA, G. (2006). A comparison between novices and experts of the velocity-accuracy trade-off in overarm throwing. *Perceptual and Motor Skills*, 103(2): 503-514.

VAN DEN TILLAAR, R. & ETTEMA, G. (2007). A three-dimensional analysis of overarm throwing in experienced handball players. *Journal of Applied Biomechanics*, 23(1): 12-19.

WAGNER, H. & MÜLLER, E. (2008). Motor learning of complex movements: The effects of applied training methods (differential and variable training) to the quality parameters (ball velocity, accuracy and kinematics) of a handball throw. *Sports Biomechanics*, 7(1): 54-71.

WAGNER, H.; KAINRATH, S. & MÜLLER, E. (2008). Coordinative and tactical parameters of team-handball throw: The correlation of level of performance, throwing quality and selected technique-tactical parameters. *Leistungssport* (trans.: *Competitive Sport*)*,* 38(5): 35-41. (In German).

WAGNER, H.; TILP, M.; VON DUVILLARD, S.P. & MÜLLER, E. (2009). Kinematic analysis of volleyball spike jump. *International Journal of Sports Medicine*, 30(10): 760-765.

WAGNER, H.; BUCHECKER, M.; VON DUVILLARD, S. & MÜLLER, E. (2010). Kinematic description of elite vs. low-level players in team handball jump throw. *Journal of Sports Science and Medicine*, 9(1): 15-23.

WAGNER, H.; PFUSTERSCHMIED, J.; VON DUVILLARD, S.P. & MÜLLER, E. (2011). Performance and kinematics of various throwing techniques in team-handball. *Journal of Sports Science and Medicine*, 10(1): 73-80.

YOTOV, I. & ARAKCHIYSKI, Z. (2012). Kinematic structure of the jump shot in a handball game. *Journal European Handball Federation,* 6(1): 1-7.

Corresponding author: Dr. Qais B. Yaseen; **Email:** Q.yaseen@najah.edu

(*Subject editor: A/Prof. Leon Lategan)*