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Relationship between Kinematic Variables of Jump Throwing and Ball Velocity in Elite Handball Players

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Abstract: The purpose of this pilot study was to evaluate the relationship between the kinematic variables of the right hand and left leg with ball velocity during jump-throwing phases in handball for better-informed training. We investigated ball velocity and the key kinematic variables of jump throwing during different throwing phases in three strides. Ten right-handed male handball professional players who had competed in the Egyptian Handball Super League participated in this study. Jump throwing performance was divided into three phases (cocking, acceleration and follow-through), which included eight events during the throwing. Five trials were captured for each player, and a 3D analysis was performed on the best trial. Results indicated that the velocity of the throwing hand was the most important variable during jump throwing, which was correlated with ball velocity during the three phases of performance in four events: Initial contact (IC) ($r = 0.66^*$), initial flight (IF) ($r = 0.63^*$), maximum height of the throwing hand (Max-HH) ($r = 0.78^*$) and ground contact (GC) ($r = 0.83^*$). In addition, the initial flight was the most important event in which players need to be using the best angles during performance, particularly the shoulder angle.

Keywords: jump throwing ability; 3D motion analysis; acceleration

1. Introduction

Team handball is an Olympic sport played worldwide at a professional level in several countries. Recently, handball has received increased attention in research studies, especially in biomechanics [1–8].

Jump throwing is an essential task in handball and is used frequently from different positions when a player shoots at the goal. As has been mentioned in earlier studies, handball players perform about 48,000 throws during the season, with the mean throwing speed of $130 \text{ km}\cdot\text{h}^{-1}$ [9], they and commonly use (73–75% of the time) jump throwing throws during the competition [5,7]. Hence, jump throwing and players' ability to accelerate the ball with the arm throw are vital demands during a handball game.

During jump throwing in handball, ball velocity and jump height range are key factors for better throwing performance [10]. Thus, most studies have investigated ball velocity [5,11,12].

Kinematic variables contribute to the velocity of the ball in order to find the fundamental procedures for improving handball players. As such, previous studies have documented the kinematic results of jump throwing performance in handball. Wagner, Buchecker, von Duvillard and Muller [7] found a significant difference of ball velocity, body height and weight between elite and lower performance levels. As well as, Wagner, Pfusterschmied, von Duvillard and Müller [5] compared the ball velocity and throwing accuracy between jump and standing throws. In addition, van den Tillaar and Ettema [8] investigated the contribution of upper-extremity, trunk, and lower-extremity movements, and van den

Tillaar [2] compared the range of motion with throwing kinematic variables. Plummer and Oliver [1] investigated the effects of fatigue on kinematic and kinetic changes of upper-extremity jump throwing.

Many kinematic experiments have studied ball throwing for team handball players and investigated the movement phases during the ball throwing [7,8,13,14]. Few studies have examined the kinematic variables effects and established relationships with ball velocity using 3D biomechanical tools. The handball coaches tend to focus on improving the throwing velocity for players [15].

Thus, through the investigation in the biomechanics of throwing velocity in elite handball players for the purpose of providing guidance to coaches and players desiring to improve this key aspect of performance, previous studies have shown a distinctive contribution of a velocity–accuracy trade-off and have concluded that kinematic variable as displacement along the velocity accuracy is achieved as an important contributed factor of decision-making. Therefore, ball velocity is considered the main factor for high quality jump throwing towards the goal [2,16,17].

In this regard, Stirn, et al. [18] opined that there are many factors contributing to the final velocity of the ball at release. To evaluate these factors, different demanding and time-consuming acquisition and analysis methods are required, including kinematic and electromyography assessments. Wagner, Pfusterschmied, von Duvillard and Müller [5] argued that the lower extremity in this type of skill plays an important role to drive the upper-extremity during performance. Therefore, throwing performance is considered to be the final outcome of an efficient kinetic chain.

The drive leg step before the take-off during the throwing jump skill could be an essential part of throwing to provide a support for the transfer of momentum through the pelvis and trunk to the dominant throwing arm. The kinematic investigation of the current study should be helpful for identifying the optimum jumping throwing mechanics. Consequently, we evaluated the relationship between ball velocity and some kinematic variables to identify key variables which should contribute to improving jump throwing performance.

Few studies have examined kinematic variable effects and established relationships with ball velocity using 3D biomechanical tools. Our goal for this study was to evaluate the correlation between key variables and throwing velocity, with the goal of providing information useful to coaches and players for improving jump-throwing performance. Therefore, we hypothesized that there would be positive and strong relationships between the kinematic variables of the right hand and left leg with ball velocity, and we determined key kinematic variables of jump throwing.

2. Materials and Methods

2.1. Subjects

Ten right-handed male handball players participated in current study (age: 20.8 ± 1.21 years; body mass: 82.8 ± 8.57 kg; height: 189.6 ± 8.65 cm, training experience: 9 years). They were part of a professional team which competed in the Egyptian Handball Super League. The study was approved by the institutional ethics committee of studies and research, and each player's consent was obtained.

2.2. Procedures

After a 15-min warm-up including general and shoulder-specific mobility exercises, as well as stretching and familiarization with the protocol, participants performed jump-throws after three running steps while positioned in front of the goal. Players were instructed to throw the ball as fast as possible. A total of five successful attempts were recorded for each player, with a one-minute rest between attempts. The best attempt, according to velocity of the ball, was selected for 3D analysis. The jump throwing skill was broken into three phases: The cocking phase, the acceleration phase, and the follow-through phase. Eight events were identified, beginning with the touch down (this event was determined when the jump leg touched the force platform starting the take-off).

The second event was the maximum ground reaction force (this event was designated as when the peak ground reaction force was achieved). Next was take-off (this event was designated as when

the jump leg left the force platform). Maximum arm cocking was designated as when the arm reached the maximum back swing. Maximum height of center of mass was defined as when the center of mass achieved maximum height.

The maximum height of throwing arm was defined as when the throwing hand was at the maximum height. Ball release was defined as when the ball was released from the throwing arm, and the last event was landing, which was designated as when the player touched down from flight during performance (Figure 1).

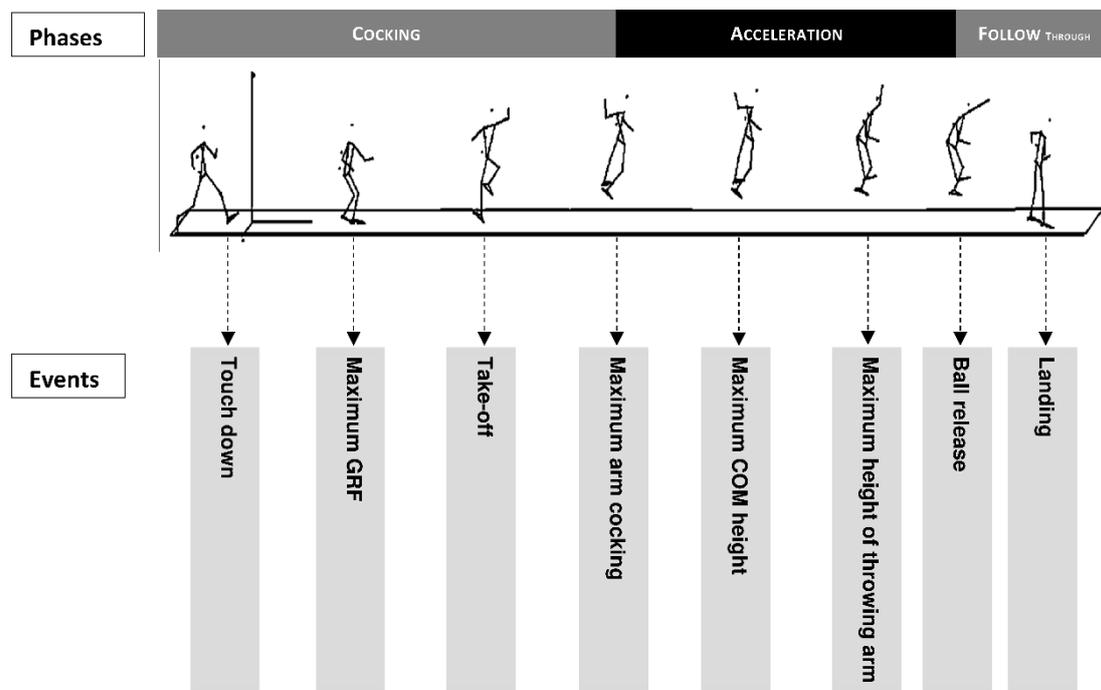


Figure 1. Jump throwing phases (cocking phase, acceleration phase, follow-through phase), and events (touch down, maximum ground reaction force (GRF), take-off, maximum arm cocking, maximum height of center of mass (COM), maximum height of throwing arm, ball release, and landing) during performance.

The kinematic variables of the right-hand (throwing arm) were measured using a 3-D motion capture system (Simi Reality motion analysis V. 9.0.6, eight synchronized Basler scA640-120gc-High-Speed Cameras were used at a 100 Hz frequency) that tracked the position of the reflective markers on anatomical landmarks according to the Hanavan model [19,20], (Figure 2). The 3D coordinates were the X (medio-lateral), Y (anterior-posterior) and Z (vertical) directions. Throwing performance was evaluated by the ball velocity [21], which was calculated by creating a rigid body of the ball using software and tracked. The angular kinematics of the joints were derived from relative angles between the two relevant segments (sagittal plane). A strain gage force platform (MP4060[®], Bertec Corporation, Columbus, OH, USA) was used to determine the touch down and maximum ground reaction force events. The standard setting of software for filtering were used, and differentiation was used to calculate the kinematics variables [22].

2.3. Statistical Analysis

The Pearson coefficient of correlation was used to determine the strength of the relationships between each kinematic variable and ball velocity during each of the jump throwing phases (Table 1). Asterisk signs above the number represent significant differences between kinematic variables and ball velocity, and (*) indicates $p \leq 0.05$ for statistical procedures (SPSS 21, V. 21 Statistics for Windows. IBM Corp, Armonk, NY, USA).

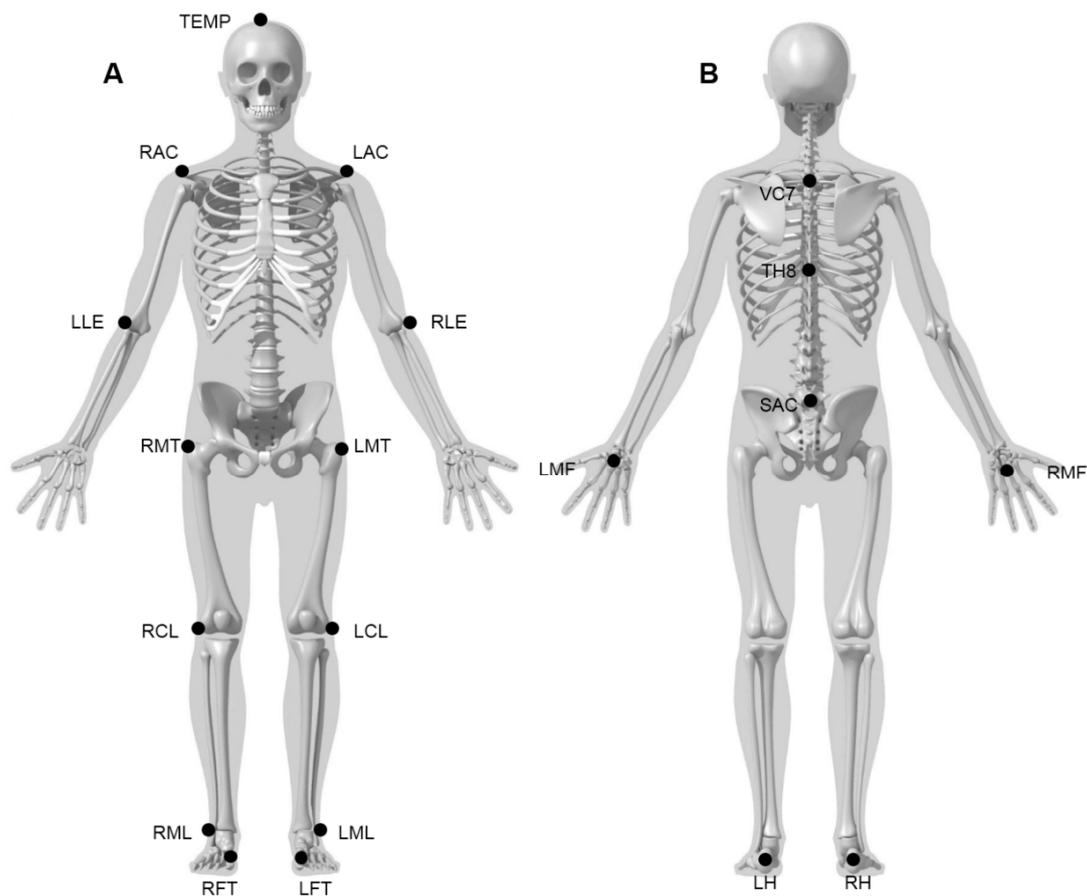


Figure 2. Full body marker set in (A) anterior (B) posterior view. The markers were placed at tempus head (TEMP), acromion left/right (LAC, RAC), epicondylus lateralis (elbow lateral) left/right (LLE, RLE), trochanter major left/right (LMT, RMT), Condylus lateralis left/right (LCL, RCL), malleolus lateralis left/right (LML, RML), foot tip left/right (LFT, RFT), vertebra C7 (VC7), vertebra Th8 (TH8), mid spina Iliaca posterior superior (SAC), middle finger base joint left/right (LMF, RMF), and heel left/right (LH, RH).

3. Results

The relationships between kinematic variables and ball velocity are shown in Tables 1 and 2 during each jump throwing phase (see Figure 1).

Table 1 provides the Pearson correlation coefficients between ball velocity and kinematic variables (displacement, velocity, and acceleration) at three investigated phases for eight events. No significant correlation was seen between ball velocity and right-hand kinematic variables during the cocking phase (displacement) and the acceleration phase (acceleration).

During the cocking phase, the ball velocity showed moderate correlations with the right arm velocity at initial contact (IC) (Y and R coordinates) ($r = 0.66$, $r = 0.63$) and initial flight (IF) (Y) ($r = 0.63$). Furthermore, there was a relatively strong correlation ($r = 0.72$) between the right arm acceleration at maximum ground reaction force (Max-GRF) (Y) and ball velocity. Through the acceleration phase, right arm displacement at maximum height of body (GC—ground contact) during flight (Max-GCH) (Y) had the highest correlation coefficients during this phase ($r = 0.83$) with ball velocity, and at release ball (RB) (Y) a strong correlation ($r = 0.77$) was observed. Likewise, ball velocity had moderate and strong correlations with the right arm displacement at maximum height of the throwing hand (Max-HH) (R) and RB (R), ($r = 0.67$ and $r = 0.79$, respectively). In addition, strong and moderate correlations were seen during the acceleration phase between velocity of the right hand and the ball velocity at Max-HH (Y) and Max-HH (R), ($r = 0.78$ and $r = 0.70$, respectively). As shown in Table 1 during the follow-through

phase, the kinematic variables of the right hand such as the displacement at GC (Y, R) and velocity at GC (Y) had the highest correlation coefficients ($r = 0.84$, $r = 0.88$, and $r = 0.83$, respectively). A moderate correlation was observed between ball velocity and the right-hand acceleration ($r = 0.68$) at GC (Y) during this phase.

Table 1. Correlation between right-hand center of mass kinematic variables and ball velocity during jump throwing phases in handball. N = 10.

Variables (Unit)	Coordinates	Cocking Phase			Acceleration Phase				Follow-Through Phase
		IC	Max-GRF	IF	Max-BC	Max-GCH	Max-HH	RB	GC
Displacement (m)	X	-0.23	0.10	0.15	0.21	0.05	0.14	-0.04	-0.11
	Y	-0.27	0.32	0.34	0.57	0.83 *	0.63	0.77 *	0.84 *
	Z	0.56	-0.43	-0.27	-0.00	0.13	0.04	-0.25	-0.04
	R	0.49	-0.54	-0.21	0.04	0.22	0.67 *	0.79 *	0.88 *
Velocity (m/s)	X	-0.41	-0.05	0.15	-0.18	0.27	-0.28	-0.37	-0.39
	Y	0.66 *	0.20	0.63 *	0.22	0.51	0.78 *	-0.40	0.83 *
	Z	0.22	-0.00	-0.18	0.21	0.27	0.43	-0.51	0.50
	R	0.63 *	-0.04	0.09	0.26	0.41	0.70 *	0.04	-0.04
Acceleration (m/s ²)	X	0.56	0.62	-0.02	0.01	-0.05	-0.50	0.22	-0.34
	Y	0.40	0.79 *	0.24	-0.35	0.24	0.35	-0.57	0.68 *
	Z	-0.59	0.31	0.28	-0.40	0.26	0.08	0.43	0.30
	R	0.17	-0.54	-0.22	-0.42	0.11	-0.01	0.44	0.17

Note: Coordinates: X (medio-lateral), Y (anterior-posterior), Z (vertical), and R (resultant); IC: Initial contact (end of last step); Max-GRF: Maximum Ground Reaction force; IF: Initial flight; Max-BC: Maximum back cooking; Max-GCH: Maximum height of body GC during flight; Max-HH: Maximum height of the throwing hand GC during flight; RB: Release ball; GC: Ground contact; * Correlation were considered significant at $p < 0.05$.

Table 2. Correlation between right hand and left leg angular variables and ball velocity during jump throwing phases in handball.

Joint (Unit)	Variables (Unit)	Cocking Phase			Acceleration Phase				Follow-Through Phase
		IC	Max-GRF	IF	Max-BC	Max-GCH	Max-HH	RB	GC
Right elbow	Angle (°)	-0.21	0.22	0.08	0.03	-0.07	-0.64 *	-0.29	-0.33
	Velocity (°/s)	-0.20	-0.30	0.05	-0.41	-0.07	-0.11	-0.56	-0.03
	Acceleration (°/s ²)	0.44	-0.05	-0.05	0.25	0.20	0.55	-0.28	0.19
Right shoulder	Angle (°)	0.49	-0.51	-0.32	-0.38	-0.45	-0.31	-0.32	-0.63
	Velocity (°/s)	0.30	-0.32	0.69 *	-0.18	0.13	-0.37	-0.67 *	0.27
	Acceleration (°/s ²)	-0.59	0.31	0.67 *	0.55	0.28	-0.07	0.25	-0.21
Left hip	Angle (°)	0.07	0.33	0.41	0.32	0.28	0.36	0.22	0.73 *
	Velocity (°/s)	0.44	-0.27	-0.51	-0.05	-0.37	0.35	-0.21	-0.26
	Acceleration (°/s ²)	-0.30	-0.65 *	-0.67 *	0.24	-0.44	-0.23	-0.26	-0.14
Left knee	Angle (°)	0.16	-0.57	-0.01	-0.29	0.23	0.28	-0.07	-0.34
	Velocity (°/s)	0.46	-0.26	0.13	-0.02	0.28	-0.26	-0.09	-0.67 *
	Acceleration (°/s ²)	-0.15	-0.51	-0.18	0.22	-0.50	-0.33	0.08	-0.52
Left ankle	Angle (°)	-0.71 *	-0.80 *	0.30	0.01	-0.17	-0.10	-0.50	-0.57
	Velocity (°/s)	-0.03	0.06	0.38	-0.09	0.36	-0.61	0.08	-0.45
	Acceleration (°/s ²)	0.56	0.16	-0.53	-0.01	0.13	-0.19	0.37	-0.30

Note: IC: Initial contact (end of last step); Max-GRF: Maximum ground reaction force; IF: Initial flight; Max-BC: Maximum back cooking; Max-CGH: Maximum height of body GC during flight; Max-HH: Maximum height of the throwing hand GC during flight; RB: Release ball; GC: Ground contact; * Correlation were considered significant at $p < 0.05$.

The Pearson correlation coefficients between ball velocity with the right hand and left leg angular variables (angle, velocity, acceleration) during the three phases can be seen in Table 2. There were

no significant correlation coefficients observed between the ball velocity and the kinematic variables of right elbow during all phases except a moderate negative performance score ($r = -0.64$) of angle at Max-HH during the acceleration phase. Likewise, during the follow-through phase, the velocity of the left knee had a moderate negative correlation ($r = -0.67$) at GC. Right shoulder velocity and acceleration had a moderate correlation with ball velocity at IF during the cocking phase ($r = 0.69$, $r = 0.67$, respectively). At RB during the acceleration phase, the right shoulder velocity had a moderate negative correlation ($r = -0.67$). Left hip acceleration during the cocking phase had a moderate negative correlation with ball velocity at Max-GRF and IF ($r = -0.65$, $r = -0.67$, respectively), and the angle of the left hip had a strong correlation ($r = 0.73$) at GC during the follow-through phase. The angle of left ankle during the cocking phase had a strong negative correlation with performance at IC and Max-GRF ($r = -0.71$, $r = -0.80$, respectively).

4. Discussion

The current study examined the relationships between ball velocity and kinematic variables during the jump throwing of elite handball players. The main aim was to determine the relationships between ball velocity and right hand (throwing hand) linear kinematics, as well as right arm and left leg (take-off leg) angular kinematics during three investigated phases over eight events.

The results in Table 1 show that the kinematic variables at maximum ground reaction force, maximum height of body center of gravity during flight, release ball and ground contact events were correlated strongly with ball velocity. These findings support a previous study which indicated important kinematic variables of the standing throw in handball [23].

The analysis of the cocking phase in our study indicated a moderate correlation between ball velocity and the velocity of the right hand at IC (Y, R) and IF (Y). This finding indicates that the primary velocity of elbow and the initial flight with the ball increased the ball velocity. During the same phase, the right-hand acceleration had a strong correlation with ball velocity at Max-GRF (Y). This strong correlation indicates that the Max-GRF during the jump throwing improved the horizontal velocity of the right hand (elbow and wrist joint) before ball release, which led to improving the arm swing during throwing.

The displacement of the right hand during the acceleration phase was strongly correlated with ball velocity at Max-CGH (Y), RB (Y) and RB (R). In addition, the Max-HH (R) during this phase correlated moderately with the ball velocity. This finding implies that maximum height of body GC and the dominant throwing hand increase the kinematic requirements of the hip and shoulder to maintain a high velocity of ball and performance; van den Tillaar and Ettema [24] showed some kinematic changes during overarm throwing related to the elbow extension and internal rotation.

Furthermore, the velocity of the right hand correlated strongly with Max-HH (Y) and moderately with Max-HH (R). The positive correlation with ball velocity and maximum heights of the throwing hand (Y, R) coordinates during the acceleration phase implies that arm motion continues until ball release time, which generates a ball rotation around the central axis, increases and generates the required release ball velocity. This supports the study of Werner, et al. [25], who suggested that the arm acceleration phase is the dynamic phase between the maximum external shoulder rotation and the instant of ball release.

During the follow-through phase, the results indicated that a higher correlation between ball velocity and the displacement of the right hand at GC (Y and R), and the velocity of the right hand had a high correlation at GC (Y). However, a moderate correlation was seen during this phase with the acceleration of the right hand at GC (Y). A strong correlation of displacement and velocity were found during this phase, so we suggest that when players perform the jump throw, they must increase their movement horizontally to enable forward movement at the landing. Hirashima, et al. [26] indicated that the ability of skilled throwers to optimize the throwing arm event of inertia during the arm cocking and arm acceleration phases highlights the importance of the arm movement to reach a high ball velocity.

Our findings in Table 2 indicate that the moderate negative correlation between ball velocity and the right elbow angle during the Max-HH event. This finding indicates that the smaller angle at the elbow joint assists in the improvement of a higher ball velocity at release for longer throwing. This finding supports previous studies [8,15,23], which indicated that the elbow extension and internal rotation velocity were factors for fast shoulder throwing, wherein about 73% of the contribution of ball velocity was based on the maximal internal rotation velocity of the shoulder and maximal elbow extension during the throw.

A moderate correlation was seen between the ball velocity and the right shoulder velocity and acceleration variables at IF during the cocking phase. In addition, a moderate correlation was observed between the right shoulder velocity at RB and ball velocity during the acceleration phase. This finding indicates that player who moves forward at take-off also maintains a higher projection angle with the wrist hyperextension at the ball release, which leads to a higher flight time style. This result is seen in the correlation between ball velocity and the releasing of ball during the acceleration phase. During the acceleration phase, the maximal angular velocities of the elbow extension, wrist flexion, and the internal rotation of the shoulder joint make a substantial contribution to overarm throwing in team handball [23].

The left hip and right hand had moderate correlations with ball velocity at Max-GRF and with IF events during the cocking phase. During the follow-through phase at GC, a strong correlation was observed between the angle of the left hip and ball velocity. These negative correlations with ball velocity during the cocking phase indicated that handball players were using a greater angle of projection to reach for optimum position before releasing the ball and generate a required power with the throwing arm. Thus, higher velocities of the arm joints could be produced [23], which could result in higher external rotation while throwing. This finding confirmed that the movement of the large body segments such as legs and trunk assist with the reduction of energy in the throwing arm in order to reduce the loads, especially on the shoulder and elbow [25,27,28].

The ball velocity had a moderate correlation with the velocity of the left knee at GC during the follow-through phase and the left ankle angle at the IC and Max-GRF events during the cocking phase (Table 2). The negative correlation between left knee velocity with ball velocity implies that players had a greater knee flexion in the follow-through phase for preparation for landing. Olsen, et al. [29] and Koga, et al. [30] reported that landing after a jump throwing with the knee near full extension was important to prevent ACL injuries in team handball players.

It should be noted that these findings were derived from a small sample of homogenous elite handball players. We selected elite players because we wanted data from high-level performance. A small sample was used in this pilot study in order to evaluate the utility of this approach. Finding strong and moderate correlations in a small, homogenous sample suggests that these findings are very conservative. We hope that future investigations will expand on these preliminary findings.

A limitation was that the sample size in the present study was small (ten right-handed male handball players), and we analyzed the best attempt of the five successful performed attempts. All our participants were elite, meaning that our sample was homogenous, making correlations more challenging to identify. We were willing to accept these limitations in this pilot study because our goal was to identify the correlations for top performers, since it was assumed that these participants represent the best performances. However, future investigations should recruit a larger number of participants and/or increase the number of attempts.

5. Conclusions

Based on the main findings from this study, the velocity of the right hand at IC and IF events (anterior–posterior direction) correlated with ball velocity during the cocking phase as a preparation phase that accelerates the arm throwing. The increases in right-hand acceleration at Max-GRF, Max-HH events (anterior-posterior direction) led to the improvement of the horizontal velocity of the right hand (elbow and wrist joint) before the RB event achieved the highest ball velocity. Furthermore, the results

indicated that the change in angular variables of shoulder joint are greater than those of the elbow. Thus, we recommend that, in training programs, coaches focus on increasing their player's movement horizontally to enable forward movement at the landing when evaluating the performance level of handball players.

Also, we recommend that coaches to use special power and reaction time exercises to reduce the dominant foot contact time at the jump moment and before throwing the ball. This would allow the player to jump higher before the ball release event and keep the maximum velocity of the ball while throwing performance.

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