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Article *in* Sports Biomechanics · September 2020

DOI: 10.1080/14763141.2020.1800072

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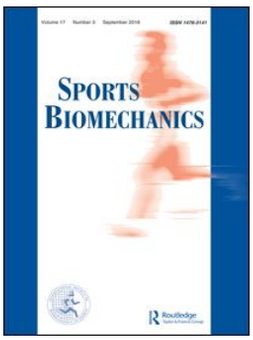

Sports Biomechanics

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rspb20

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To cite this article: Francisco Javier Moreno , Jose Luis Hernández-Davó , Juan Antonio García , Rafael Sabido , Tomás Urbán & Carla Caballero (2020): Kinematics and performance of team-handball throwing: effects of age and skill level, Sports Biomechanics, DOI: 10.1080/14763141.2020.1800072

To link to this article: https://doi.org/10.1080/14763141.2020.1800072

SPORTS BIOMECHANICS
https://doi.org/10.1080/14763141.2020.1800072

Kinematics and performance of team-handball throwing: effects of age and skill level

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ABSTRACT

To assess the influence of age and skill level on handball throwing kinematics and performance, 126 participants were distributed into groups according to their skill level (elite or recreational) and age group (U12, U16 or +18). Each participant performed three sets of 10 throws, aiming to hit a target (40 × 40 cm) located in the right corner of the goal. During testing, kinematic data were recorded and throwing performance (accuracy and velocity) was measured. Results showed greater throwing velocity in the elite compared to recreational groups, whereas no differences were found for throwing accuracy. The elite U16 and +18 groups displayed higher segment velocities (hand, arm and pelvis) than the recreational groups. The participation of proximal segments was higher in older groups, showing the more skilled players (U16 and +18) greater pelvis velocities (1.62–1.75 vs 1.02–1.22 m/s). The increased velocity of the distal joints (hand peak velocity: 13.56 ± 1.65 vs 10.67 ± 1.98 m/s) are responsible for the difference in throwing velocity between the elite and recreational U12 groups. Several correlations were found between joint kinematics and throwing velocity. Coaches could use these results during training, to optimise specific throwing training.

ARTICLE HISTORY
Received 23 March 2020
Accepted 16 July 2020

KEYWORDS
Team sport; accuracy; velocity; recreational; elite

Introduction

Team handball is an Olympic sport which has seen an increased participation over the past decades, with the International Handball Federation reporting more than 19 million players worldwide in 2009 (Karcher & Buchheit, 2014). Team handball involves intermittent activities including fundamental movement skills such as running, jumping and throwing (Ortega-Becerra et al., 2018; Wagner et al., 2014). Throwing performance plays an important role in the interactive concept of team games (Gromeier et al., 2017). Overarm throwing is the major action in team handball, which is used to pass the ball to a teammate and to score goals (Van den Tillaar & Cabri, 2012). Thus, it has been established as a determinant factor for winning a team handball match (Rousanoglu et al., 2015). As the winning squad in a team handball match is the team that scores the most goals, both throwing velocity and accuracy are responsible for success in this sport

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(Ortega-Becerra et al., 2018). As a consequence, several studies have used velocity and accuracy as quantitative measurements of throwing performance (Rousanoglu et al., 2015; Urbán et al., 2015; Wagner et al., 2011) with greater throwing velocity and accuracy observed in elite players compared to non-elite players (Granados et al., 2007; Moss et al., 2015).

The factors that influence the throwing action can be divided into tactical (i.e., characteristics of the defensive players and the goalkeeper), physical (i.e., muscular strength) and technical (i.e., movement pattern) aspects. Rousanoglu et al. (2015) reported that the foreknowledge of the target position and the temporal constraint influence handball throwing performance in a different way between expert and novice team handball players. Among the physical variables, both lower-limb muscular strength (i.e., countermovement jump ability and maximal squat strength) and upper-limb strength (i.e., bench-press strength) are positively related to handball throwing velocity (Chelly et al., 2010; Gorostiaga et al., 2005; Ortega-Becerra et al., 2018). A great amount of research has focused on the kinematic variables that influence throwing performance (Wagner et al., 2014). Specifically, the focus has been placed on the velocity of the joints involved in the throwing action, which are known to affect throwing performance. The most analysed joints include from more proximal segments, such as pelvis, trunk and shoulder, to more distal ones, as the elbow, the forearm and the wrist. The angular velocity of shoulder internal rotation (Van den Tillaar & Ettema, 2007), elbow extension (Van den Tillaar & Ettema, 2004) and wrist flexion (Wagner et al., 2010) have been shown to differ between team handball players of different performance levels. Van den Tillaar and Ettema (2009a, 2009b) suggested that timing action of several body segments, including lower-body, trunk, and hip joints, is important for maximising throwing velocity. In this line, the importance of the proximal-to-distal movement pattern in the team handball throwing action has been previously reported (Wagner et al., 2012), highlighting the importance of a correct energy transfer to the more distal segment of the throwing action (e.g., hand). Consequently, several differences in the timing action of the joints involved in the standing throw between players of different skill levels have been found. Specifically, joint actions such as trunk, pelvis and shoulder external rotation as well as wrist flexion are significantly different between elite and less experienced players (Wagner et al., 2012).

The influence of joint kinematics on throwing velocity has been widely studied. Thus, it is possible to find comparisons in throwing velocity between players of different genders (Van den Tillaar & Cabri, 2012), skill levels (Wagner et al., 2010, 2012) and ages (Ortega-Becerra et al., 2018). However, although these studies have reported kinematic differences between groups, to the best of the authors' knowledge, no research has reported a correlation analysis to assess how these kinematic variables are related to throwing velocity. Apart from throwing velocity, throwing performance is also linked to throwing accuracy. Despite the importance of throwing accuracy in team handball performance, there is a lack of research focused on the potential kinematic variables that influence throwing accuracy. In addition, it is also understudied how players' age plays a role in the kinematics and performance of team handball throwing. Thus, there is a need of research in this topic, as the knowledge of how elite athletes perform the throwing action movement could be used by coaches to provide appropriate feedback to younger players.

Therefore, due to the limited available data found in the literature, the aim of this study was to compare throwing performance and kinematics between players of different ages (i.e., U12, U16 and +18) and skill levels (elite and recreational). For performance variables (ball velocity and accuracy), the authors hypothesised that independently of the age group, elite players will show higher ball velocities and better accuracy than their respective recreational players. We also hypothesised that more skilled players will show a greater participation (represented by higher velocities) of the proximal segments involved in the throwing action (i.e., pelvis). Regarding the influence of age on kinematic variables during throwing, we hypothesised that significant differences will be found between the U12 group and the other two groups (U16 and +18) in all kinematic variables, while the differences between U16 and +18 groups could not be significantly different.

Methods

Participants

One hundred and twenty-six male team handball players volunteered to participate in the study, all of whom were right-handed. The sample was divided into six groups according to the players' age and level of experience (see Table 1 for demographic information). All participants were fully informed of the potential risks of the study, and all signed a written informed consent prior to the testing session. The experimental procedures used in this study were in accordance with the Declaration of Helsinki and were approved by the Ethics Research Committee of the Miguel Hernández University (IRB Approval: 2013.83.E.OEP).

Table 1. Descriptive data of the participants.

Group	*n*	Age (years)	Height (m)	Weight (kg)
U12 Recreational	22	12.4 ± 0.7	1.61 ± 0.08	45.5 ± 6.5
U12 Elite	21	12.3 ± 0.6	1.64 ± 0.07	48.6 ± 6.0
U16 Recreational	19	15.7 ± 0.3	1.78 ± 0.06	64.3 ± 6.7
U16 Elite	19	15.9 ± 0.4	1.87 ± 0.06*	64.3 ± 10.7
+18 Recreational	20	26.5 ± 5.1	1.78 ± 0.07	75.7 ± 14.5
+18 Elite	25	23.3 ± 3.4	1.92 ± 0.09*	87.7 ± 14.2*

* significant difference with their recreational counterparts.

Procedures

Before the measurements, each player completed a 10-min warm-up including jogging, dynamic stretching and passing. Then, a specific warm-up including submaximal and maximal velocity throws was performed. The testing session consisted of 30 standing throws, distributed into three sets of 10 throws, aiming at a target (40 × 40 cm) located in the right corner of the goal (Figure 1). The standing throw was performed from a 7-m distance to the goal, with participants placing their feet in parallel to the goal line and a self-selected width. Participants rested 30 s between sets and 5 s between throws. Participants were instructed to 'throw at the highest speed and with the highest accuracy possible, aiming at the target'. The balls (IHF size 1, 2 or 3 depending on the

players' age; Molten, Japan) were given to the participant one by one for each throw. In order to assess throwing performance, a Sports Radar SR3600 (Homosassa, FL, USA) was used to record the maximum ball velocity in each throw with a sensitivity of ±0.44 m/s. The radar was placed behind the players and oriented, so it was pointing at the target. The goal and surrounding areas were covered with a net. The net position where the ball impacted was used to establish the accuracy of each throw. To measure this, the goal was filmed during the evaluation with a digital camera (50 Hz sampling frequency; HDR-SR8E; Sony, Tokyo, Japan) to establish the point of impact for each throw. The camera was placed at a height of 3 m above the floor, pointing at the target (Figure 1).

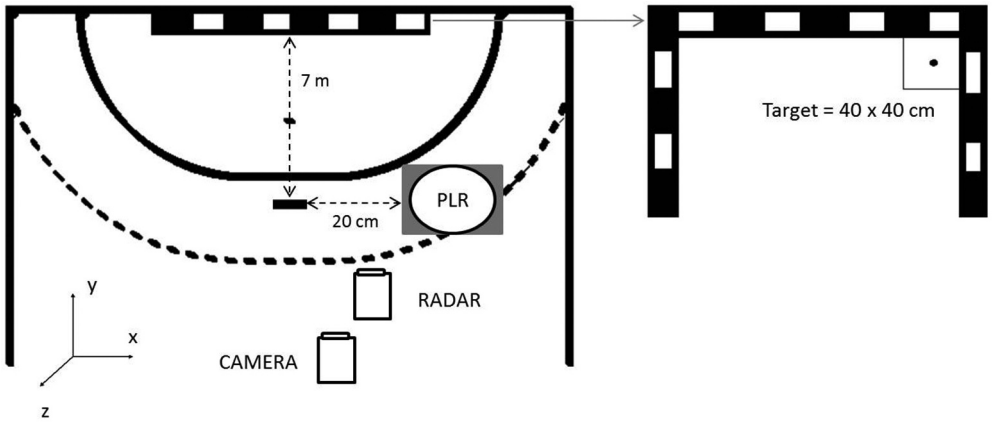

Figure 1. Handball court and instrument distribution.

Regarding the kinematic variables, the displacement (anteroposterior (AP), mediolateral (ML) and vertical (V) measured on the y, x and z axes, respectively) of the right arm and right pelvis were recorded using the PolhemusLiberty^{TM} electromagnetic tracking system at 240 Hz sampling frequency. Three sensors were firmly placed on each participant, located on the right deltoid tuberosity of the humerus bone, on the middle of the back of the right hand, and on the right iliac crest (Figure 2).

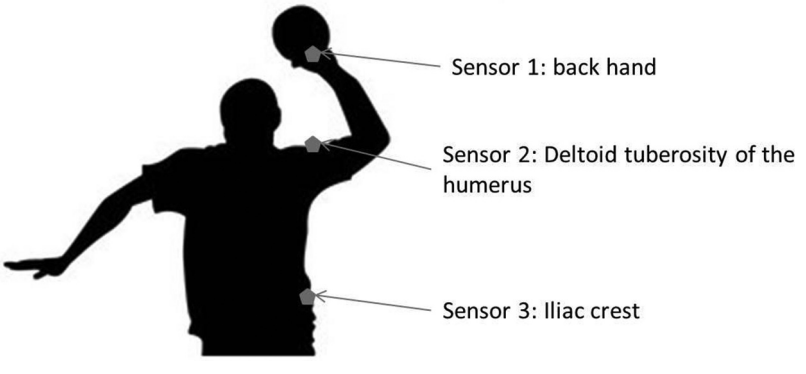

Figure 2. Sensors placement.

Data analysis

The speed of the ball was computed as the mean maximum ball velocity. To compute the accuracy of the throw, the mean radial error (MRE) was calculated. The MRE was measured as the average absolute distance to the target point (the centre of the square was considered the target point; see Figure 1). To measure the distance from the ball to the centre of the target, video digitalisation of the ball impact was computed with a Matlab (version 7.11; Mathworks, Natick, MA, USA) routine for the calculation of real-space Cartesian coordinates. The square and the target point was drawn on a sheet that was hanged just behind the goal posts. As the sheet covered the goal and the external part, ball impact was able to be located even after missed throws.

All participants were asked to place their hands together in front of their body before every throw. Kinematic variables were analysed from the moment that the participant separated their hands to initiate the throw until the moment of the ball release. For velocity data, the variables analysed were the peak velocity of the hand in each axis (AP, ML and V), and the resultant velocity. For position data, the variables used for analysis were hand and pelvis position in three-time moments: (a) 100 ms before ball release; (b) 50 ms before ball release; and (c) at the moment of ball release. Considering that the kinematic parameters of the hand position were affected by the anthropometric characteristics of each participant, the spatial data of the dominant hand were considered relative to the individual range of motion using the pelvis marker. Thus, between-segment spatial data in the AP, ML and V axes were calculated. For all the performance and kinematic variables analysed in the study, the mean of the 30 repetitions was calculated and used for statistical analysis.

Statistical analysis

All data were analysed using the SPSS statistical package (version 22.0; SPSS Inc., Chicago, IL, USA). A Kolmogorov–Smirnov test was conducted to test the deviation of the data from the normal distribution. A two-way (skill level [2; recreational vs elite], age [U12 vs U16 vs +18]) factorial ANOVA was used to analyse the main effect as well as the interactions of skill level and age on kinematic and performance variables. Pairwise comparisons were performed using a Bonferroni *post-hoc* test. The Cohen's *d* effect size (ES) was calculated to assess the magnitude of the differences and interpreted as trivial (<0.25), small (0.25–0.50), moderate (0.5–0.8) and large (>0.8). Pearson correlations were performed to analyse the relationship between kinematic variables and throwing performance, and interpreted as negligible (<0.30), small (0.30–0.50), moderate (0.50–0.70) high (0.70–0.90) and very high (>0.90) (Hinkle et al., 2002). Statistical significance was set at $p< 0.05$.

Results

In Table 2, the results of the ANOVA for all the variables used in the study are shown. There were significant main effects for skill level on 13 of the 18 variables analysed. There were also significant main effects for age on 14 of the 18 variables analysed. Finally, nine variables showed a significant skill level × age interactions.

The influence of the skill level on throwing performance and the kinematic variables by age group is shown in Figure 3. In summary, despite a trend for better accuracy in elite groups, no significant between groups differences in throwing

accuracy were found. Ball velocity and hand peak velocity was highly influenced by the skill level. In the same way, arm and pelvis peak velocity was greater in elite groups, with higher ES in U16 and +18 groups. For kinematic variables of the hand, greater velocities in the AP axis were found in the elite groups, while in the ML axis, the recreational groups tended to show greater values. Multiple between-groups comparisons are presented in Table 3.

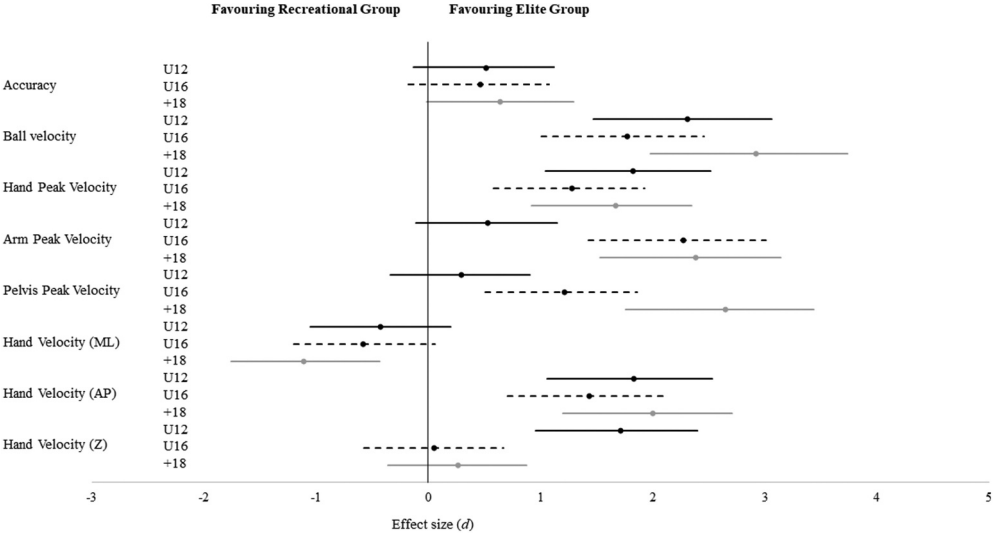

Figure 3. Comparison of throwing performance and throwing kinematics between recreational and elite players of different ages.

Table 2. Results of the factorial ANOVA.

	Skill level		Age		Skill level × Age	
Variable	F_1	*p*	F_2	*p*	F_2	*p*
Accuracy	2.724	0.101	2.042	0.134	2.773	0.066
Ball Velocity	165.533	<0.001	22.843	<0.001	3.995	0.021
Hand Peak Velocity	84.913	<0.001	23.763	<0.001	2.078	0.130
Arm Peak Velocity	130.993	<0.001	14.034	<0.001	2.266	0.108
Pelvis Peak Velocity	51.382	<0.001	5.164	0.007	10.150	<0.001
Hand Velocity (ML)	14.988	<0.001	4.987	0.008	1.854	0.161
Hand Velocity (AP)	89.558	<0.001	21.614	<0.001	3.127	0.048
Hand Velocity (V)	9.743	0.002	6.777	0.002	5.111	0.007
Hand/Pelvis pre100ms (ML)	68.026	<0.001	15.415	<0.001	1.272	0.284
Hand/Pelvis pre50ms (ML)	28.090	<0.001	8.269	<0.001	0.807	0.449
Hand/Pelvis release (ML)	0.018	0.893	4.025	0.021	1.878	0.158
Hand/Pelvis pre100ms (AP)	41.511	<0.001	10.397	<0.001	4.096	0.019
Hand/Pelvis pre50ms (AP)	30.481	<0.001	8.757	<0.001	8.919	<0.001
Hand/Pelvis release (AP)	0.111	0.739	0.383	0.683	9.012	<0.001
Hand/Pelvis pre100ms (V)	0.003	0.958	1.734	0.181	19.599	<0.001
Hand/Pelvis pre50ms (V)	5.324	0.023	6.034	0.003	6.317	0.003
Hand/Pelvis release (V)	22.874	<0.001	16.415	<0.001	1.088	0.340

AP = anteroposterior; ML = mediolateral; V = vertical

Table 3. Pair-wise comparison in throwing performance and kinematic variables between players of different ages and/or skill levels.

	Group					
Variable	U12 Recreational	U12 Elite	U16 Recreational	U16 Elite	+18 Recreational	+18 Elite
Accuracy (m)	0.40 ± 0.12	0.35 ± 0.07	0.36 ± 0.07	0.39 ± 0.06	0.44 ± 0.08	0.38 ± 0.10
Ball velocity (km/h)	45.1 ± 5.5	58.9 ± 6.4[a]	51.2 ± 5.7a	63.4 ± 7.9[ac]	51.7 ± 6.5[ad]	71.7 ± 7.2[abcde]
Hand Peak Velocity (m/s)	10.69 ± 1.91	13.75 ± 1.41[a]	12.82 ± 1.43[a]	14.38 ± 0.96 [c]	13.22 ± 1.27[a]	15.48 ± 1.43[abcde]
Arm Peak Velocity (m/s)	4.08 ± 1.60	4.74 ± 0.71[a]	4.15 ± 0.65[b]	5.60 ± 0.63[abc]	4.14 ± 0.68[d]	5.69 ± 0.62[be]
Pelvis Peak Velocity (m/s)	1.10 ± 0.26	1.18 ± 0.29	1.11 ± 0.23	1.49 ± 0.38[abc]	1.01 ± 0.19[d]	1.66 ± 0.29[abce]
Hand Velocity (ML) (m/s)	2.02 ± 1.86	1.28 ± 1.53	1.56 ± 1.47	0.67 ± 1.58	3.44 ± 1.31[abcd]	1.32 ± 2.35[e]
Hand Velocity (AP) (m/s)	8.89 ± 1.41	11.44 ± 1.38[a]	10.70 ± 0.91[a]	12.02 ± 0.93[ac]	10.65 ± 0.95[ad]	13.17 ± 1.51[abcde]
Hand Velocity (V) (m/s)	3.97 ± 1.41	6.29 ± 1.30[a]	5.95 ± 2.09[a]	6.04 ± 1.67[a]	6.25 ± 1.43[a]	6.71 ± 2.01[a]

AP = anteroposterior; ML = mediolateral; V = vertical a = significantly different from U12 recreational; b = significantly different from U12 elite; c = significantly different from U16 recreational; d = significantly different from U16 elite; e = significantly different from U18 recreational.

Table 4. Pair-wise comparison of the relative position of the hand with respect to the pelvis before the ball release and at the moment of the ball release.

		Hand/Pelvis (ML)			Hand/Pelvis (AP)			Hand/Pelvis (V)		
		Pre100ms	Pre50ms	Release	Pre100ms	Pre50ms	Release	Pre100ms	Pre50ms	Release
U12	Recreational	−2.4 ± 10.2	−11.4 ± 8.9	−18.3 ± 10.4	−40.1 ± 6.3	−20.5 ± 10.3	14.6 ± 14.5	40.1 ± 6.3	50.9 ± 6.9	63.0 ± 6.1
	Elite	9.9 ± 10.4[a]	−3.5 ± 11.5[a]	−16.7 ± 9.8	−42.3 ± 9.1	−20.0 ± 9.9	26.0 ± 7.5[a]	51.9 ± 6.9[a]	61.1 ± 6.2[a]	72.9 ± 5.8[a]
U16	Recreational	8.7 ± 9.3[a]	−4.8 ± 9.9	−12.9 ± 12.5	−40.6 ± 5.1	−19.9 ± 5.8	22.2 ± 8.9	52.2 ± 6.1[a]	61.5 ± 8.0[a]	74.1 ± 8.7[a]
	Elite	25.4 ± 9.3[abc]	8.8 ± 6.1[abc]	−9.3 ± 12.1	−52.5 ± 8.2[abc]	−32.6 ± 6.9[abc]	15.5 ± 11.5[bc]	42.7 ± 11.5[bc]	60.0 ± 12.0[a]	79.8 ± 10.1[abc]
+18	Recreational	−1.9 ± 7.6[bcd]	−9.3 ± 7.6[d]	−14.8 ± 5.4	−42.3 ± 5.2[d]	−20.9 ± 4.9[d]	22.2 ± 5.7	50.5 ± 5.9[ad]	60.9 ± 5.9[a]	73.8 ± 6.0[ad]
	Elite	17.9 ± 14.4[abce]	−0.3 ± 14.1[ade]	−20.9 ± 15.9[d]	−52.3 ± 5.9[abce]	−32.1 ± 5.9[abce]	19.4 ± 8.5	47.9 ± 8.0[a]	62.2 ± 6.5[a]	79.0 ± 9.6[abce]

AP = anteroposterior; ML = mediolateral; V = vertical a = significantly different from U12 recreational; b = significantly different from U12 elite; c = significantly different from U16 recreational; d = significantly different from U16 elite; e = significantly different from U18 recreational.

Table 5. Correlations between kinematic variables and throwing performance.

		Height	Body Mass	Accuracy	Hand Peak Velocity	Arm Peak Velocity	Pelvis Peak Velocity	Hand Velocity (ML)	Hand Velocity (AP)	Hand Velocity (V)
U12	Accuracy	−0.168 (p= 0.312)	−0.260 (p= 0.282)	-	−0.218 (p= 0.161)	0.045 (p= 0.775)	0.177 (p= 0.257)	0.199 (p= 0.202)	−0.258 (p= 0.094)	−0.219 (p= 0.158)
	Ball Velocity	0.169 (p= 0.310)	0.335 (p= 0.160)	−0.088 (p= 0.573)	0.712 (p< 0.001)	0.378 (p= 0.012)	0.510 (p < 0.001)	−0.065 (p= 0.677)	0.775 (p < 0.001)	0.490 (p= 0.001)
U16	Accuracy	0.094 (p= 0.678)	0.141 (p= 0.392)	-	0.143 (p= 0.384)	0.098 (p= 0.554)	0.266 (p= 0.102)	−0.014 (p= 0.935)	0.183 (p= 0.265)	−0.068 (p= 0.679)
	Ball Velocity	0.416 (p= 0.044)	0.029 (p= 0.859)	0.222 (p= 0.175)	0.526 (p= 0.001)	0.399 (p= 0.012)	0.524 (p= 0.001)	−0.154 (p= 0.349)	0.668 (p < 0.001)	−0.048 (p= 0.770)
U18	Accuracy	−0.246 (p= 0.167)	−0.273 (p= 0.084)	-	−0.341 (p= 0.025)	−0.195 (p= 0.211)	−0.069 (p= 0.659)	0.069 (p= 0.660)	−0.323 (p= 0.034)	−0.139 (p= 0.374)
	Ball Velocity	0.425 (p= 0.014)	0.411 (p= 0.018)	−0.177 (p= 0.257)	0.690 (p < 0.001)	0.784 (p < 0.001)	0.779 (p < 0.001)	−0.310 (p= 0.043)	0.702 (p < 0.001)	0.040 (p= 0.797)

AP = anteroposterior; ML = mediolateral; V = vertical

Table 6. Correlations between the relative position of the hand with respect to the hip with throwing performance.

		Hand/Pelvis (ML)			Hand/Pelvis (AP)			Hand/Pelvis (V)		
		Pre100ms	Pre50ms	Release	Pre100ms	Pre50ms	Release	Pre100ms	Pre50ms	Release
U12	Accuracy	−0.175 (p= 0.260)	−0.172 (p= 0.271)	−0.115 (p= 0.461)	−0.016 (p= 0.920)	−0.090 (p= 0.568)	−0.178 (p= 0.252)	−0.261 (p= 0.091)	−0.296 (p= 0.054)	−0.249 (p= 0.107)
	Ball Velocity	0.581 (p < 0.001)	0.391 (p= 0.009)	0.032 (p= 0.840)	−0.401 (p= 0.008)	−0.251 (p= 0.105)	0.154 (p= 0.324)	0.419 (p= 0.005)	0.509 (p= 0.001)	0.627 (p< 0.001)
U16	Accuracy	0.055 (p= 0.740)	0.062 (p= 0.709)	−0.024 (p= 0.887)	−0.194 (p= 0.237)	−0.207 (p= 0.205)	−0.164 (p= 0.318)	−0.077 (p= 0.641)	−0.114 (p= 0.491)	−0.073 (p= 0.657)
	Ball Velocity	0.359 (p= 0.025)	0.197 (p= 0.229)	−0.093 (p= 0.571)	−0.652 (p < 0.001)	−0.632 (p < 0.001)	−0.390 (p= 0.014)	−0.354 (p= 0.027)	−0.321 (p= 0.047)	0.083 (p= 0.617)
+18	Accuracy	−0.193 (p= 0.215)	−0.147 (p= 0.346)	−0.048 (p= 0.758)	0.192 (p= 0.216)	0.205 (p= 0.187)	0.044 (p= 0.780)	0.061 (p= 0.695)	0.072 (p= 0.647)	−0.021 (p= 0.893)
	Ball Velocity	0.681 (p < 0.001)	0.420 (p= 0.005)	0.021 (p= 0.893)	−0.492 (p= 0.001)	−0.504 (p= 0.001)	−0.086 (p= 0.581)	−0.258 (p= 0.095)	0.001 (p= 0.997)	0.242 (p= 0.117)

AP = anteroposterior; ML = mediolateral; V = vertical

Data of the position of the hand relative to the pelvis at the moment of the ball release and in the instants prior to the ball release are shown in Table 4. In both the ML and the AP axes, multiple between-groups differences were found 100 and 50 ms prior to ball release, while at the moment of ball release there were only few differences. In contrast, in the V axis, the position of the hand relative to the pelvis showed more differences at the moment of ball release.

The correlations between kinematic variables and throwing velocity in the different age groups are presented in Tables 5 and 6. In all age groups, hand, arm, and pelvis peak velocities were positively correlated with ball velocity. In addition, hand velocity in the AP axis was highly correlated with ball velocity in all groups, while hand velocity in the V axis was positively correlated with ball velocity in the U12 group. Hand peak velocity and hand velocity in the AP axis were negatively correlated with throwing accuracy in the +18 group.

When analysing the relative position of the hand with respect to the pelvis, significant correlations between throwing velocity and the hand/pelvis position prior to ball release were found in the ML (positive correlations) and AP axes (negative correlations) in all groups. In the V axis, the U12 group showed negative correlations and the U16 group a positive correlation with throwing velocity. At the moment of ball release, a negative correlation was found between throwing velocity and hand/pelvis position in the AP axis. A positive correlation was found between hand/pelvis position in the V axis at the moment of ball release and throwing velocity in the U12 group. Regarding correlations with throwing accuracy, only in the U12 group, the relative position of the hand with respect to the pelvis in the V axis 50 ms prior to the ball release showed significant correlations.

Discussion and implications

The aims of this study were to compare kinematic data among team handball players of different ages and skill levels, and to investigate the kinematic variables related to team handball throwing performance. The main findings of the present study were that throwing accuracy did not differ between groups, independent of age and skill level, but throwing velocity was significantly influenced by both age and skill level. This faster ball-throwing velocity was accompanied by increased velocities of the tested segments. In addition, independently of the axis analysed, the position of the hand relative to the pelvis prior to the ball release differed significantly between groups and was correlated with throwing velocity.

Throwing velocity is considered essential for scoring success. In the present study, the elite +18 group showed significant greater throwing velocities than all the other groups. The values for absolute throwing velocity (72 km/h) recorded for the elite +18 group are consistent with those reported in previous studies using a standing throwing action: 70.2 km/h (Granados et al., 2007), 74 km/h (Serrien et al., 2015), 77 km/h (Van den Tillaar & Ettema, 2009a), and 80.3 km/h (Wagner et al., 2011). In addition, the difference in throwing velocity values between the elite +18 group and the elite U16 group (approximately 11%) and between the elite +18 and the recreational +18 groups (approximately 17%) observed in the present study are similar to previous studies which used the standing throwing action (Gorostiaga et al., 2005; Wagner et al., 2018). Although not measured in the present study, some potential explanations for the greater throwing velocities when comparing elite vs recreational groups can be provided. For example, it could be hypothesised that the greater number of hours of practice, as well as

a higher fitness level, including greater levels of upper- and lower-body strength, may influence the greater throwing velocities displayed by the elite groups (Ortega-Becerra et al., 2018). Together with the differences in height and body mass found in the present study, additional differences in players' anthropometrical characteristics may also explain between groups differences in throwing velocity (Moss et al., 2015; Vila & Ferragut, 2019). Therefore, additional variables like lean body mass, hand size and body segments' length are encouraged to be collected in further studies in order to address this issue.

The other performance variable measured in the current study, throwing accuracy, did not differ significantly between the groups. The MRE values observed in the elite groups (from 0.35 to 0.39 m) are similar to those reported in previous studies with elite U16 players (0.40 m) (García et al., 2017). However, the lack of differences between the different skill level groups observed in the present study differs from other studies, which showed that expert team handball players displayed greater accuracy than novice players (Rousanoglu et al., 2015). This inconsistency may be explained by the difference in the skill level of the recreational groups between the studies. In the study by Rousanoglu et al. (2015), the novice players had completed a 4-month handball course, while in the present study the recreational group comprised participants that consistently trained no more than 2 days per week, but who did not compete. In addition, the specific task demands in the present study may have influenced the values of throwing accuracy found. Players in the present study were instructed to throw at highest possible speed, which could have negatively influence throwing accuracy. In this line, Van den Tillaar and Ettema (2003) showed that the highest throwing accuracy is not reached at maximal speed, but approximately at 85%. Further, Vila et al. (2020) reported through match-analysis that higher throwing effectiveness (e.g., scoring success) was not achieved during maximal speed throws. Additionally, participants in the present study performed the throwing action without goalkeeper, which could have hidden between-group differences. García et al. (2017) showed that the presence of a goalkeeper had a significantly greater effect on a less experienced (U16) group compared to a more experienced group (U18), but there were no differences in throwing accuracy between these same groups when throwing in the absence of a goalkeeper. Therefore, we hypothesise that the greater training background of the recreational groups, along with the specific task demands used in the current study may explain the lack of significant differences in throwing accuracy between the elite and the recreational groups.

Many kinematic variables showed significant differences when comparing elite and recreational players in the U16 and the +18 groups. The two U12 groups only showed a difference in the hand peak velocity, which may be reflecting this variable as a key point for optimal throwing technique. These results agree with previous research showing that hand action is linked to throwing velocity (Jöris et al., 1985) and accuracy (Hore et al., 1995). In addition, the velocity of the hand in the AP axis differed significantly between elite and recreational players of all age groups, showing elite players greater values. Increases in hand velocity in the forward direction may be linked to an optimised transfer of energy in the goal-directed movement, which has been reported to be a key point to achieve higher throwing velocities (Wagner et al., 2011). Both U16 and +18 elite players increased participation of proximal segments as a strategy to increase throwing velocity. This statement is supported by the significantly greater values for pelvis peak velocity observed in the elite U16 and the +18 groups. These results are in line with those showed

by Van den Tillaar and Ettema (2009a) and Wagner et al. (2010), highlighting the importance of proximal segment actions (e.g., pelvis rotation, trunk tilt) in the handball throwing action. Previous research has suggested that the major part of the work during a handball throw is performed in the last 50 ms of the movement (Jöris et al., 1985). In this line, several differences in joint kinematics 100 and 50 ms prior to ball release were found in the present study. Further, Van den Tillaar and Ettema (2009a, 2009b) suggested that not only the velocity of the segments but the timing of the joints involved in the movement influence throwing velocity. Consequently, differences in segment timings have been previously reported when comparing team handball players of different skill level (Wagner et al., 2012).

Correlation analysis between kinematic variables and throwing performance showed that throwing accuracy was not correlated with any variable. The lack of relationships between throwing speed and throwing accuracy is not in line with Vila et al. (2020) reported a negative relationship between throwing velocity and effectiveness. However, they measured effectiveness through a percentage of scoring goals, and not by throwing accuracy as in the present study. Our results are in line with Wagner et al. (2011) who reported similar values of throwing accuracy despite using different throw actions, and therefore, different kinematics. Regarding ball velocity, several kinematic variables showed significant relationships. All hand, arm, and pelvis peak velocities were positively correlated with ball velocity. Nevertheless, the magnitude of this relationship changes over the years, as in the U12 group, the higher relationship was found for hand peak velocity and the lower for the pelvis peak velocity, while in the +18 group the relationship between the proximal segments showed the highest relationship. Thus, it seems that the changes in the movement pattern in older groups, characterised by greater velocities of the proximal segments, would lead to a greater distal velocity and, therefore, to an increased ball velocity. An optimisation in the timing of joint actions leading to a better energy flow from proximal-to-distal segments cannot be discarded (Jöris et al., 1985). Hand velocity in the AP axis showed high values of significant correlations with ball velocity, which reflects the aforementioned importance of the energy transfer in the goal-directed movement (Wagner et al., 2011).

No relationships were found with throwing accuracy when analysing the influence of the position of the hand relative to the pelvis. Nevertheless, the relative position in the ML axis in the instant prior to the ball release was significantly correlated with ball velocity in the +18 group. Thus, it seems that throwing technique change over the years, showing the elite players a greater lateral distance between the hand and the hip in the moments prior to ball release. This greater distance would increase the angular momentum, leading to higher velocities in the distal segments, and consequently, a greater ball velocity. In both the U12 (pre 100 ms) and U16 (pre 100 and pre 50 ms) groups, the relative position of the hand with respect to the pelvis in the AP axis was also correlated with ball velocity. Compared with an advanced position, a more backward position of the hand in the early moments prior to ball release would need a faster forward movement to achieve the position of ball release in the same time point, which allows for greater ball velocity. Altogether, these relationships are in line with Van den Tillaar and Ettema (2009a), who reported greater values of range of motion and maximal velocity of shoulder rotation and trunk tilt as a characteristic of faster throws. Finally, the position of the hand relative to the pelvis in the V axis before the ball release was also correlated

with throwing velocity in the U12 group. The greater throwing height may be reflecting a compensatory strategy to increase throwing velocity (Van den Tillaar & Ettema, 2009a). This last fact may be linked to a greater radius from the shoulder to the hand, which involves higher linear velocities and consequently, greater ball velocity.

The current study presents some limitations. By measuring kinematic data from additional joints, together with measures of joint timings, would have provided supplementary information. Because we have found some differences in players' height and body mass due to both skill level and age, measures of some anthropometric measures (e.g., body composition, arm, and hand length) would have allowed additional data analysis and interpretation. Finally, the sample only included male players, and therefore there could be some limitations to transfer the interpretations to female populations.

Conclusion

By analysing three age groups and two different skill levels, the present study provides important information of kinematic evolution over the years. Youth players seem to prioritise hand speed and throwing height to increase throwing speed. However, over the years, the importance of proximal segments actions to enhance throwing speed is increased. The greater joint velocities were accompanied with changes in movement pattern, highlighting the importance of a great range of motion of the hip, trunk, and shoulder to increase throwing performance. No between-groups differences were found in throwing accuracy, which may be explained by the specific task demands of the study (i.e., throwing at maximal speed and without goalkeeper). The results of the present study could be used by coaches to optimise the learning process of the team handball throwing action.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This study was made possible by financial support from Economy and Competitiveness Ministry of Spain, project cod. DEP2010-19420 and DEP2013-44160-P.

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