ORIGINAL ARTICLE

Upper-limb joint kinematics analysis of accuracy dart throwing at different vertical targets between different level dart players

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ABSTRACT

Darts has evolved from a traditional pub room game to a professional sport. More and more people worldwide are participating in the sport of dart throwing. In order to enhance throwing performance, it is important to understand the mechanics of precise dart throwing techniques. Therefore, the purpose of this study was to investigate the fine-tune control of joint kinematics with different vertical targets between different skill levels to understand how to increase the success rate and generate precise fine-tuning of the motor system. Eight advanced players and eight intermediate players participated in this study. A motion capture system measured the kinematic data of the arm during throwing. The results indicated a significant interaction in shoulder internal rotation velocity (p = .031) and elbow supination velocity (p = .047) between advanced and intermediate groups with the different vertical targets. When intermediate players threw darts at different vertical targets, changes in shoulder internal rotation velocity and elbow supination velocity were observed. Conversely, these phenomena were not present in the advanced group. Additionally, we found that dart accuracy or light weight throwing requires an more angle of elbow pronation and generate high angular velocity of wrist palmar flexion during the release process. Based on the findings of this study, these results could provide a reference guide for dart throwing to improve the throwing performance.
Keywords: Biomechanics, Throwing kinematics, Throwing technique, Dart throwing motion.

Cite this article as:
Huang, T-Y., Hamill, J., Yang, H., & Tang, W-T. (2024). Upper-limb joint kinematics analysis of accuracy dart throwing at different vertical targets between different level dart players. *Journal of Human Sport and Exercise, 19*(3), 722-736. https://doi.org/10.55860/x54dcc14

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Submitted for publication January 09, 2024.
Accepted for publication February 19, 2024.
Published April 06, 2024.
JOURNAL OF HUMAN SPORT & EXERCISE ISSN 1988-5202.

doi: https://doi.org/10.55860/x54dcc14

INTRODUCTION

Since the 1970s, darts or dart-throwing has rapidly changed from a traditional pub room game into a professional throwing sport. The change was enabled by the creation of the British Darts Organisation (BDO). It was actively promoted by the World Darts Federation (WDF) and the Professional Darts Corporation (PDC) to gain international recognition for darts as a major sport (Davis, 2018). Presently, dart throwing sport is played in over 70 countries in the world owing to advances in sports science and widespread media coverage (World Darts Federation website).

The classic dart game, also known as the "*01 game*," has gained significant popularity in the world of dart throwing (Vasiljev, Rubin, Milosavljevic, & Vasiljev, 2017). In this game, players aim to throw darts at a dartboard with 82 different areas, each offering specific points when hit (Dehghani, Montazeri, Givi, Guerrero, & Dhiman, 2020). The game begins with a set score, usually 301, 501, 701, or 901 points, and the objective was to reduce the score to exactly 0 points by hitting specific marked areas of the dartboard. To achieve this, players must not only target the bull's-eye accurately but also throw darts precisely at various areas on the dartboard. Consequently, studying the kinematics of the upper limb during dart throwing at different targets becomes crucial (Wunderlich, Heuer, Furley, & Memmert, 2020).

Advanced dart players may develop an optimal strategy for fine-tuning the control of joint kinematics to release the dart with an appropriate hand trajectory when aiming at different vertical targets on the dartboard. Previous studies on ball throwing have shown that throwing baseballs to different vertical areas involves changes in hand trajectory controlled by shoulder elevation (Watts, Pessotto, & Hore, 2004). It is important to note that the overarm throwing motion in those studies differs from the dart-throwing action. Dart throwing involves a lighter weight and more intricate finger grip motion (Watts et al., 2004). As of now, no study has investigated how advanced dart players adjust their fine-tune control of their joint kinematics during dart throwing to target different vertical areas on the dartboard.

Additionally, advanced dart players may develop superior biomechanical characteristics in joint kinematics to achieve consistent throwing movement to intermediate players. Previous studies suggest avoiding excessive flexion angular velocity in the wrist during release for accuracy (Hirashima, Kudo, & Ohtsuki, 2003; Hirashima, Ohgane, Kudo, Hase, & Ohtsuki, 2003). However, some research emphasized releasing rigid control over wrist joint kinematics for learning accurate throwing skills (Button, MacLeod, Sanders, & Coleman, 2003; Vereijken, Emmerik, Whiting, & Newell, 1992). The specific wrist joint kinematics in accurate dart throwing and differences between advanced and intermediate players remain unclear. Further research is needed to understand the development of mastery in dart throwing. Such insights could enhance training programs to improve dart players' accuracy and consistency.

Therefore, the purpose of this study was to investigate the fine-tune control of joint kinematics of players of different skill levels throwing at different vertical targets in order to understand how to increase their success rate and generate precise fine-tuning of the motor system. We hypothesized that beyond the elevation of the shoulder joint for the purpose of adjusting the throwing trajectory, the elbow and wrist joints are likely to play integral roles in the fine-tune control mechanics at different vertical targets and advanced groups could have different joint kinematics during dart release than intermediate groups for accuracy dart throwing. A thorough understanding of these biomechanical characteristics of advanced dart player will help to develop new training programs for improving skill of the dart throwing.

MATERIAL AND METHODS

Participants

A total of 16 dart players that come from the Chinese Taipei Darts Federation (CTDF) were recruited in the experiment. All participants were divided into advanced and intermediate groups based on the Phoenix rating (reference). According to Phoenix Rating, ratings range from 1 to 30 and rankings over 19 were generally considered advanced groups. Thus, in our study, eight dart players participated in the experiment as an advanced group. Their characteristics were: height: 175.50 ± 5.83 m; mass: 73.50 ± 16.77 kg; experience: 5.63 ± 4.10 years; rating: 21.75 ± 2.43. The other eight dart players participated as an intermediate group. Although their Phoenix rating did not reach 18, their rating still has the level of over 10. Their characteristics were: height: 175.13 ± 4.58m; mass: 74.75 ± 15.14 kg; experience: 4.86 ± 4.06 years rating:14.13 ± 2.42. All participants signed a written informed consent form prior to the experiment. The study was approved by the institutional review board of Fu Jen Catholic University in Taiwan and all procedures were in accordance with the Declaration of Helsinki.

Experimental setup

Dart throwing motion was captured by eight cameras motion capture system (Eagle, Motion Analysis Corporation., Santa Rosa USA) placed to surround the participant. The motion capture sampling frequency was 200 Hz (Tran, Yano, & Kondo, 2019). Before the experiment began, the research team performed static (L frame) and dynamic (T wand) corrections to calibrate the experimental environment. If the average 3D residual was below 0.5 mm, the calibration was accepted. The three -dimensional coordinate system was identified as the X-axis (anteroposterior) was aligned front to back and toward target direction, while the Z-axis (longitudinal) was aligned vertically upward. The Y-axis (mediolateral) was aligned left to right (Figure 1).

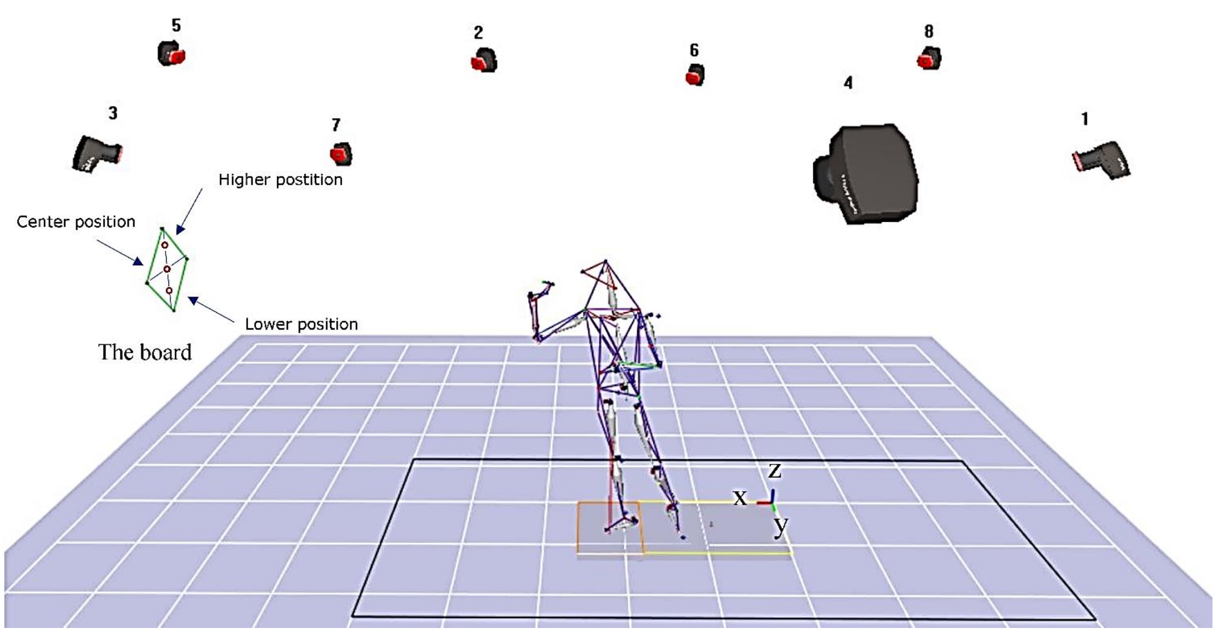

Figure 1. Dart experimental setup: Description of relative position of the cameras and different target position. The three -dimensional coordinate system was identified as the X-axis (anteroposterior) was aligned front to back and toward target direction, while the Z-axis (longitudinal) was aligned vertically upward. The Y-axis (mediolateral) was aligned left to right.

Procedures

The total of 41 reflective markers (diameter, 10–12 mm) were placed on the participant anatomical landmarks bilaterally, dart and target. The markers were attached to the top head, the 7th cervical vertebra (C7), acromioclavicular joint, trigonum scapulae, angulus inferior, later/medial epicondyle, radial/ulnar styloid, third metacarpal, anterior superior iliac spines, posterior superior iliac spines, great trochanters, thighs, knees, medial aspects of knee, shanks, ankles, medial aspects of ankles, toes, heels. Additionally, to identify the actual location by each of the darts on the board, reflective tape was also attached to the dart. The front and back ends of the dart was wound reflective tape (Tran et al., 2019). Although the provided darts were slightly different, the participants said that they had been able to adapt to it through several practice throws. In warm-up stage, participants were required to warm up sufficiently. According to the WDF dart rules, participants were asked to stand in front of the throwing line and the distance from the throwing line to the board was 2.37 m. Then, the height of the centre of the bull's-eye was set 1.73 m above the floor. Following a self-directed 15 min - 30 min warm-up and familiarization period, dart throwing proceeded. In evaluation stage, to confirm the success of the grouping, participants were asked to perform fifteen sets throws (three throws each set) to evaluation of their throw performance. In throwing stage, participants were asked to throw to 3 different heights target positions, which were in the 20-point area (higher position), the bull's-eye (centre position) and the 3-point area (lower position) respectively (Figure 1). Each position performed three throws, average value of three trials were represented the joint kinematics parameters on different position for each participant.

Data processing

The dart throwing movement was processed using a specialized motion capture software (Cortex 7.2, Motion Analysis Corp., Santa Rosa, CA). Cortex software had built-in Virtual Markers (centre of dart, target position and centre of joint) and skeleton (humerus, forearm, and hand segment). The raw marker positions were filtered by a zero-lag second-order Butterworth filter (cutoff frequency 20 Hz). The data were then exported into Microsoft Excel™ to derive the parameters.

Determination of performance assessment

To evaluate dart throwing performance, we analysed the success rate and absolute the vertical error (Nasu, Matsuo, & Kadota, 2014; Tran et al., 2019). The success rate was defined as the ratio of the number of throws hit the bull's-eye to the total number of throws for each subject. The absolute the vertical error was determined by the Euclidean distance between centre position and final dart's position on the dartboard.

Determination of throw movement phase

The dart throwing motion was divided into four phases (aiming, backward move, acceleration, and follow-through) based by previous study (Rezzoug, Hansen, Gorce, & Isableu, 2018). The aiming phase involves directing attention towards the target, succeeded by a backward motion in which the elbow undergoes slight flexion. Concluding this phase, elbow flexion velocity reach a point of equilibrium at zero. The acceleration phase was start from flexion to extension at the elbow joint and it ends with the instant of dart release. The instant of dart release was defined as the moment when the distance exceeded a pre-determined threshold between dart centre position and the thumb marker based by previous studies (Tran et al., 2019). The follow-through signifies the termination of the arm movement, characterized by the gradual deceleration and eventual cessation of articular joint movements. In that study, the analysis was focused on the acceleration phase (Figure 2).

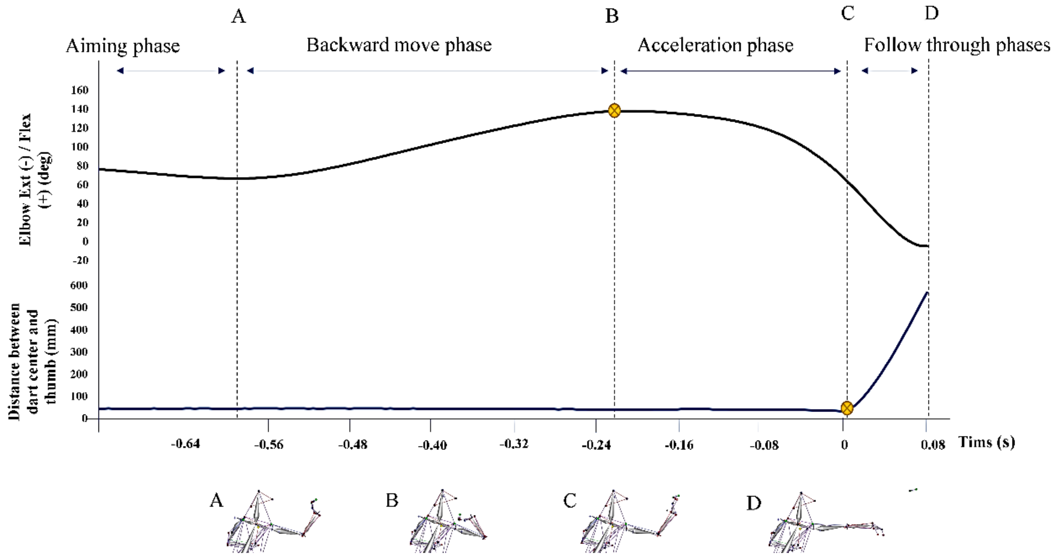

Figure 2. Illustration of dart throw phase definition from a representative participant. Backward move phase is from A to B. Acceleration phase is from B to C. Follow through phases is from C to D. (A) represents the kinematics of the elbow flexion onset (from flexion to extension at elbow joint), and (B) represents the elbow flexion reaches the maximum angle. (C) represents the dart was released (distance of the dart centre relative to the thumb finger exceeded a pre-determined threshold). (C) represents elbow joint full extension.

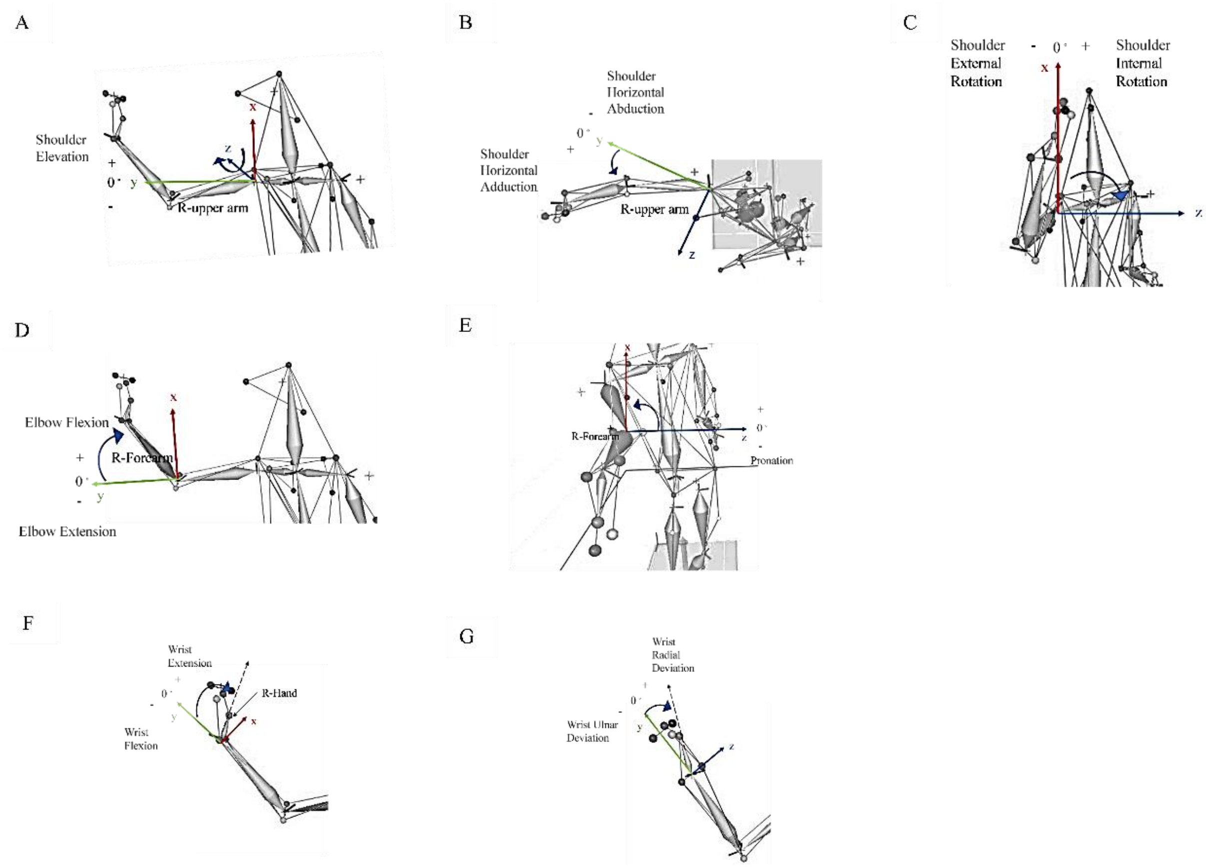

Figure 3. Illustrate the definition of joint angle of the local coordinate system dart throwing. A) Shoulder elevation; B) Shoulder horizontal abduction–adduction; C) Shoulder internal-external rotation; D) Elbow flexion–extension; E) Forearm pronation-supination; F) Wrist flexion–extension; G) Wrist radial-ulnar deviation.

Determination of the kinematics of the upper-limb

The upper extremity kinematic included the shoulder, elbow, and wrist joint. This study examined joint linear displacement and the joint angle amplitudes during acceleration phase of throwing dart. Further, joint rotation angle and angular velocity were evaluated at instant of dart release. Joint coordinate system (JCS) was calculated using the Cortex 7.2 software. According to the recommendations of the International Society of Biomechanics (ISB), the motions of the shoulders, elbows and wrists were described as follows (Wu et al., 2005). The glenohumeral joint motions included flexion–extension (shoulder elevation), horizontal abduction–adduction and internal-external rotation. The elbow joint motions included flexion–extension and forearm pronation-supination. The finally, the wrist motions included radial-ulnar deviation and flexion–extension. The rotation sequence of glenohumeral joint was modified Z-X-Y sequence (Šenk & Cheze, 2006). Local coordinate system was described in figure 5 for each joint motion.

Statistical analyses

All results are expressed as the mean ± standard deviation (SD) and were statistically analysed using SPSS 20.0 (SPSS Inc., Chicago, IL, USA). The Kolmogorov–Smirnov test was used to analyse the normality of the data. When we found that the data were not normally distributed, we used a Mann Whitney test. The results, however, showed that our data were normally distributed by the Kolmogorov–Smirnov test. Thus, the performance outcome was analysed using t-test. A two-way repeated measured ANOVA design was used to examine the interaction of different vertical target and different level player in dart and joint kinematics parameters. When an interaction was found, a one-way ANOVA was applied to determine the effect of targets independent variable on the kinematic variable does depend on the level of the skill independent variable. A Bonferroni's multiple comparison test was used for analysis whenever a significant main effect was found. The significance level was set at $p < .05$.

RESULTS

Performance outcome

The dart throw success rates resulted in significant differences between the advanced and intermediate groups for the different vertical targets (Table 1). The advanced groups achieved significantly higher success rates than the intermediate groups, regardless of the target area.

Table 1. Comparing the throw performance that throw to the different target between the advanced and intermediate groups.

Success rate o (%)	Advanced	Intermediate	*t*	*p*
High target	65.83 ± 10.95	45.00 ± 16.62*	2.961	.010*
Centre target	61.67 ± 18.08	42.50 ± 13.77	2.385	.031*
Low target	78.33 ± 9.25	50.83 ± 7.91	6.385	.000***

*Note. *p < .05, ***p < .001; SD: Standard Deviation.*

Dart kinematics

The dart release position and velocity in three-dimensional space is presented in Table 2. The study showed that throwing at different vertical targets results in adjusting the dart release position and dart release speed in the vertical direction (Z-axis), When a player throws a dart to a target that is higher than the centre of the target, the release dart point will be positioned higher in space and closer to the body. Conversely, when a darts player throws a dart to a target that is lower than the centre of the target, the release dart point will be placed lower in space and further away from the body. The dart release velocity also shows the same phenomenon.

Table 2. The dart release position and velocity at three-dimensional space between different target (t (higher, centre, lower)) and different level (advanced, intermediate).

		Advanced group		
		HT	**CT**	**LT**
Position (mm)	X-axis	1724 ± 70.51	1751 ± 79.48	1761 ± 79.47
	Y-axis	320.9 ± 74.58	322.3 ± 71.47	321.5 ± 65.96
	Z-axis	1734 ± 5978	1698 ± 55.09	1661 ± 51.17
Velocity (mm/s)	Vx -axis	5557 ± 301.5	5676 ± 286.7	5679 ± 320.0
	Vy-axis	4.80 ± 231.1	-24.19 ± 235.3	-6.92 ± 238.6
	Vz-axis	1976 ± 161.1	1587 ± 172.9	1308 ± 162.6
Resultant		5905 ± 292.4	5901 ± 293.6	5835 ± 318.4
		Intermediate group		
		HT	**CT**	**LT**
Position (mm)	X-axis	1690 ± 95.98	1703 ± 102.5	1728 ± 93.54
	Y-axis	331.9 ± 46.45	322.7 ± 42.80	321.8 ± 40.90
	Z-axis	1764 ± 22.98	1729 ± 23.61	1693 ± 21.51
Velocity (mm/s)	Vx -axis	5784 ± 341.0	5804 ± 444.7	5819 ± 347.2
	Vy-axis	-68.17±160.5	-48.65 ± 155.5	-44.98 ± 186.8
	Vz-axis	1872 ± 111.7	1562 ± 121.2	1239 ± 129.7
Resultant		6086 ± 320.3	6017 ± 413.2	5955 ± 327.8
		2-way ANOVA (*p*)		
		Interaction	**ME target**	**ME level**
Position (mm)	X-axis	.094	.000***	.398
	Y-axis	.074	.181	.896
	Z-axis	.817	.000***	.166
Velocity (mm/s)	Vx -axis	.267	.046*	.342
	Vy-axis	.140	.694	.662
	Vz-axis	.102	.000***	.356
Resultant		.469	.006**	.404

*Note. *p < .05, **p < .001; SD: standard deviation; HT: higher target; CT: centre target; LT: lower target; ME: main effect. Data was presented at mean ± SD.*

Joints kinematics

Table 3 and 4 display joint displacement and rotation amplitude during the acceleration phase. Higher targets led to a significant increase in elbow and wrist joint displacement along the vertical axis. Table 4 shows a similar trend for wrist dorsiflexion with increased rotation amplitude for higher targets.

In Table 5, angular velocity at dart release had a significant interaction, particularly for shoulder internal rotation velocity (p = .031) and elbow supination velocity (p = .047), which will be further explored. In terms of shoulder internal rotation angular velocity, the intermediate groups exhibited a significant increase when throwing at higher (133.2 ± 54.21) and centre (120.8 ± 64.51) targets compared to the lower target (94.09 ± 61.47) (F = 8.70; p = .003; η^2 = 0.55). However, the advanced groups showed no significant difference in shoulder internal rotation angular velocity between different targets (F = 0.69; p = .513; η^2 = 0.09). Regarding elbow supination angular velocity, the intermediate groups experienced a significant decrease when throwing at the lower (77.68 ± 92.51) target compared to the higher target (41.10 ± 99.98) (F = 5.43; p = .017; η^2 = 0.43). Similarly, the advanced groups did not show any significant difference in elbow supination angular velocity between different targets (F = 0.15; p = .854; η^2 = 0.02).

Table 3. The joint linear displacement during the acceleration phase between different target (higher, centre, lower) and different level (advanced, intermediate).

Linear displacement (mm)	Advanced group		
	HT	CT	LT
Shoulder on AP axis	9.18 ± 4.40	8.04 ± 3.6	8.17 ± 3.63
Shoulder on ML axis	6.08 ± 2.26	5.66 ± 2.38	5.20 ± 2.27
Shoulder on V axis	6.54 ± 3.19	5.68 ± 3.12	5.77 ± 3.16
Elbow on AP axis	10.59 ± 8.56	11.10 ± 9.3	12.83 ± 10.03
Elbow on ML axis	21.69 ± 19.74	21.18 ± 17.48	20.71 ± 17.26
Elbow on V axis	40.06 ± 14.66	37.82 ± 12.7	37.01 ± 12.76
Wrist on AP axis	236.61 ± 35.72	240.97 ± 36.30	241.33 ± 36.26
Wrist on ML axis	22.02 ± 11.77	21.69 ± 12.41	20.48 ± 9.95
Wrist on V axis	51.83 ± 18.97	36.92 ± 14.84	24.79 ± 13.21
Linear displacement (mm)	**Intermediate group**		
	HT	**CT**	**LT**
Shoulder on AP axis	9.19 ± 5.51	9.96 ± 6.35	9.77 ± 7.29
Shoulder on ML axis	4.87 ± 3.82	5.06 ± 3.75	5.35 ± 3.13
Shoulder on V axis	10.25 ± 8.66	9.51 ± 8.34	8.9 ± 6.11
Elbow on AP axis	12.71 ± 12.75	14.16 ± 16.14	13.69 ± 15.12
Elbow on ML axis	13.55 ± 7.27	13.03 ± 7.80	12.68 ± 7.73
Elbow on V axis	43.64 ± 35.36	41.12 ± 32.25	36.59 ± 25.28
Wrist on AP axis	252.60 ± 35.31	252.55 ± 40.83	252.93 ± 36.61
Wrist on ML axis	12.83 ± 7.00	13.36 ± 8.49	13.44 ± 8.36
Wrist on V axis	67.52 ± 23.12	53.71 ± 21.82	39.30 ± 16.54
Linear displacement (mm)	**2-way ANOVA (*p*)**		
	HT	**CT**	**LT**
Shoulder on AP axis	.149	.900	.656
Shoulder on ML axis	.246	.876	.704
Shoulder on V axis	.800	.154	.240
Elbow on AP axis	.472	.206	.745
Elbow on ML axis	.795	.151	.273
Elbow on V axis	.463	.028*	.858
Wrist on AP axis	.458	.459	.487
Wrist on ML axis	.298	.284	.113
Wrist on V axis	.786	.000***	.104

*Note. *p < .05, ***p < .0001, SD: standard deviation; AP = anteroposterior; ML = mediolateral; V = vertical; HT: higher target; CT: centre target; LT: lower target; ME: main effect.*

Table 4. The amplitudes of joint rotation on upper limb during the acceleration phase between target (higher, centre, lower) and level (advanced, intermediate).

Rotation amplitude (deg.)	Advanced group		
	HT	CT	LT
Shoulder Elevation	6.75 ± 3.02	7.00 ± 2.71	7.10 ± 2.79
Shoulder Int Rot	4.714 ± 2.45	4.47 ± 2.40	4.53 ± 2.66
Shoulder Hor Add	4.40 ± 2.90	3.88 ± 2.69	4.19 ± 2.57
Elbow Flexion	58.34 ± 9.43	60.58 ± 7.89	59.26 ± 9.22
Elbow Supination	9.17 ± 6.18	7.72 ± 6.07	8.57 ± 5.83

Wrist Dorsi flexion	32.84 ± 2.63	32.63 ± 3.45	31.00 ± 2.98
Wrist Rad Deviation	8.12 ± 3.30	9.52 ± 3.87	8.91 ± 3.81
Rotation amplitude (deg.)	**Intermediate group**		
	HT	**CT**	**LT**
Shoulder Elevation	6.54 ± 3.88	6.39 ± 2.68	6.14 ± 2.60
Shoulder Int Rot	5.36 ± 3.58	5.88 ± 3.51	5.34 ± 3.26
Shoulder Hor Add	1.74 ± 1.04	2.11 ± 1.22	1.83 ± 0.85
Elbow Flexion	61.81 ± 10.62	58.97 ± 10.78	58.48 ± 9.35
Elbow Supination	12.60 ± 2.93	11.33 ± 3.07	11.37 ± 2.66
Wrist Dorsi flexion	25.04 ± 2.54	24.09 ± 3.92	23.79 ± 3.14
Wrist Rad Deviation	8.89 ± 2.84	8.23 ± 3.78	8.37 ± 3.71
Rotation amplitude (deg.)	**2-way ANOVA (*p*)**		
	Interaction	**ME target**	**ME level**
Shoulder Elevation	.570	.808	.748
Shoulder Int Rot	.537	.404	.474
Shoulder Hor Add	.323	.775	.103
Elbow Flexion	.406	.177	.588
Elbow Supination	.916	.235	.913
Wrist Dorsi flexion	.494	.029*	.022*
Wrist Rad Deviation	.541	.303	.788

*Note. *p < .05, SD: standard deviation; Int Rot: internal rotation; Hor Add: horizontal adduction; Hor Abd: horizontal abduction; Wrist Rad: wrist radial; HT: higher target; CT: centre target; LT: lower target; ME: main effect.*

Table 5. The joint angle and angular velocity on upper limb at dart release between target (higher, centre, lower) and level (advanced, intermediate). The main effect is not shown if the interaction is significant ($p < .05$).

Joint Angle(deg.)	**Advanced group**		
	HT	**CT**	**LT**
Shoulder Elevation	7.20 ± 11.42	5.75 ± 12.90	4.84 ± 12.28
Shoulder Int Rot	14.84 ± 17.22	14.31 ± 17.91	14.43 ± 18.01
Shoulder Hor Add	38.70 ± 8.98	37.91 ± 9.64	38.79 ± 9.18
Elbow Flexion	69.42 ± 9.76	69.88 ± 8.50	70.77 ± 8.55
Elbow Supination	27.13 ± 9.02	27.10 ± 9.82	26.60 ± 9.41
Wrist Dorsi flexion	50.77 ± 6.40	51.45 ± 7.07	51.98 ± 5.83
Wrist Rad Deviation	15.22 ± 10.47	15.45 ± 10.31	15.86 ± 10.31
Angular velocity (deg./s)	**HT**	**CT**	**LT**
Shoulder Elevation	214.6 ± 56.42	215.5 ± 47.21	209.2 ± 53.13
Shoulder Int Rot	53.27 ± 97.52	43.86 ± 91.16	46.29 ± 88.39
Shoulder Hor Abd	-8.37 ± 47.85	-6.87 ± 47.93	-5.12 ± 48.64
Elbow Extension	478.6 ± 87.81	485.2 ± 87.34	481.2 ± 80.99
Elbow Supination	90.09 ± 137.3	83.72 ± 132.4	85.97 ± 137.2
Wrist Palmar Flexion	-1519 ± 190.8	-1503 ± 164.4	-1504 ± 167.1
Wrist Ulnar Deviation	-510.7 ± 263.9	-507.6 ± 241.6	-498.2 ± 241.7
Joint Angle(deg.)	**Intermediate group**		
	HT	**CT**	**LT**
Shoulder Elevation	3.64 ± 8.56	2.22 ± 8.92	2.71 ± 8.57
Shoulder Int Rot	5.38 ± 21.03	4.85 ± 20.52	4.89 ± 20.38

Shoulder Hor Add	39.52 ± 8.15	40.48 ± 8.41	40.70 ± 8.01
Elbow Flexion	70.03 ± 9.72	71.50 ± 8.57	72.05 ± 7.39
Elbow Supination	38.27 ± 11.15	38.08 ± 11.07	38.23 ± 9.88
Wrist Dorsi flexion	53.23 ± 11.58	53.88 ± 12.21	53.80 ± 12.06
Wrist Rad Deviation	25.45 ± 9.48	25.51 ± 9.54	25.37 ± 9.56
Angular velocity (deg./s)	**HT**	**CT**	**LT**
Shoulder Elevation	219.5 ± 100.6	209.6 ± 102.2	204.2 ± 89.33
Shoulder Int Rot	133.2 ± 54.21	120.8 ± 64.51	94.09 ± 61.47
Shoulder Hor Abd	-4.02 ± 46.17	-1.01 ± 45.86	5.48 ± 48.30
Elbow Extension	503.3 ± 149.5	499.8 ± 155.6	494.7 ± 148.9
Elbow Supination	41.10 ± 99.98	63.02 ± 121.6	77.68 ± 92.51
Wrist Palmar Flexion	-1272 ± 270.7	-1256 ± 255.7	-1255 ± 229.3
Wrist Ulnar Deviation	-661.0 ± 194.8	-673.7 ± 234.8	-690.0 ± 220.0
Joint Angle(deg.)	**2-way ANOVA (*p*)**		
	HT	**CT**	**LT**
Shoulder Elevation	.560	.000**	.569
Shoulder Int Rot	.991	.353	.340
Shoulder Hor Add	.070	.168	.691
Elbow Flexion	.768	.072	.789
Elbow Supination	.652	.767	.042*
Wrist Dorsi flexion	.669	.090	.647
Wrist Rad Deviation	.069	.205	.065
Angular velocity (deg./s)	**HT**	**CT**	**LT**
Shoulder Elevation	.320	.039*	.959
Shoulder Int Rot	.031*		
Shoulder Hor Abd	.288	.013*	.773
Elbow Extension	.363	.560	.778
Elbow Supination	.047*		
Wrist Palmar Flexion	.995	.273	.037*
Wrist Ulnar Deviation	.074	.640	.167

*Note. *p < .05, **p < .001; SD: standard deviation; Int Rot: internal rotation; Hor Add: horizontal adduction; Hor Abd: horizontal abduction; Wrist Rad: wrist radial; HT: higher target; CT: centre target; LT: lower target; ME: main effect.*

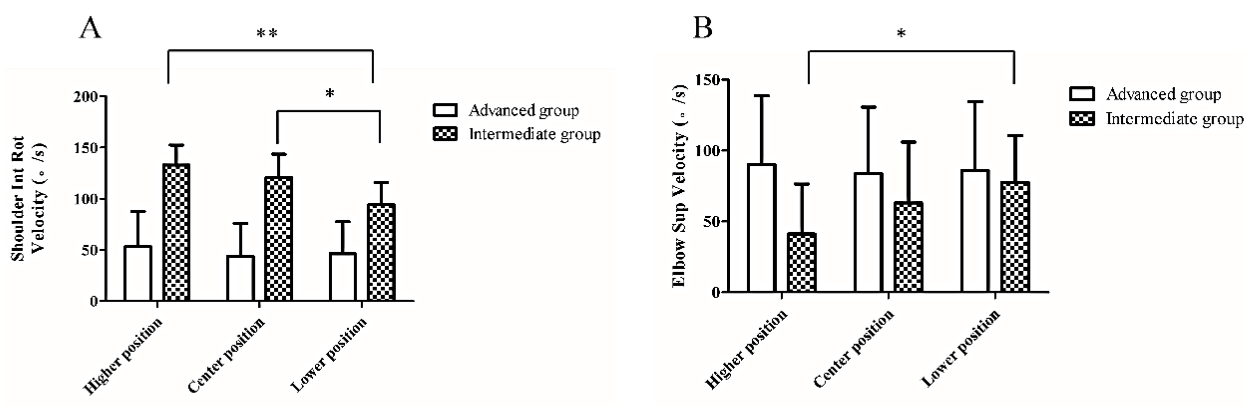

Figure 4. Comparing of the shoulder internal rotation velocity (A) and the elbow supination velocity (B) at dart release among three different target position between advanced and intermediate groups.

On the other hand, the other joint angles and angular velocity did not show significant interactions, and the main effect will be explored. Main effects were explored for different targets. Both groups showed increased shoulder elevation angle and angular velocity when throwing to higher target (Table 6).

Table 6. The main effect of kinematic for different vertical target.

	HT	CT	LT	*F*	*p*	η^2	Post Test
Dart Position (mm)							
X-axis	1707 ± 83.18	1728 ± 92.03	1745 ± 85.50	43.47	.000***	0.74	HT > LT HT > CT CT > LT
Z-axis	1749 ± 46.31	1714 ± 43.84	1678 ± 41.42	519.3	.000***	0.97	HT > LT HT > CT CT > LT
Dart Velocity (mm/s)							
Vx -axis	5671 ± 332.4	5740 ± 367.5	5749 ± 330.5	3.359	.048*	0.18	HT > LT
Vz-axis	1925 ± 144.4	1575 ± 144.8	1274 ± 144.6	612.7	.000***	0.97	HT > LT HT > CT CT > LT
Resultant	5996 ± 310.7	5959 ± 351.5	5896 ± 318.3	6.06	.006**	0.28	HT > LT
Joint displacement (deg.)							
Elbow on V axis	41.85 ± 26.22	39.47 ± 23.74	36.80 ± 19.35	4.10	.026*	0.21	HT > LT
Wrist on V axis	59.67 ± 21.98	45.32 ± 20.00	32.04 ± 16.29	148.2	.000***	0.90	HT > LT HT > CT CT > LT
Joint Rotation amplitude (deg.)							
Wrist Dorsi flexion	30.16 ± 6.04	29.32 ± 6.09	28.97 ± 6.18	4.07	.027	0.21	HT > LT
Joint angle at dart release (deg.)							
Shoulder Elevation	5.42 ± 9.92	3.99 ± 10.87	3.78 ± 10.29	8.10	.001**	0.35	HT > CT = LT
Angular velocity at dart release (deg./s)							
Shoulder Elevation	217.1 ± 78.82	212.5 ± 76.95	206.7 ± 71.05	3.59	.039*	0.19	HT > LT
Shoulder Hor Abd	-6.19 ± 45.48	-3.94 ± 45.41	0.17 ± 47.15	4.99	.013*	0.24	LT > HT

*Note. *p < .05, **p < .01, **p < .0001***; SD: standard deviation, Hor Abd: horizontal abduction, Post Test: Bonferroni's Multiple Comparison Test. HT: higher target; CT: centre target; LT: lower target; Data was presented at mean ± SD.*

Table 7. The different of joint kinematic parameter was showed between advanced group and intermediate group (mean ± SD).

	During the acceleration phase			
	Advanced group	Intermediate group	*p*	*E*
Joint Rotation amplitude (deg.)				
Wrist Dorsi flexion	32.79 ± 3.62	26.17 ± 6.13	.000 ***	
	At dart release			
	Advanced group	Intermediate group	*p*	*E*
Joint Angle (deg.)				
Elbow Supination	26.94 ± 9.01	38.19 ± 10.24	.000 ***	1.16
Angular velocity (deg./s)				
Wrist Palmar Flexion	1509 ± 166.9	1261 ± 241.4	.000 ***	1.19

*Note. ***p < .001; SD: Standard Deviation.*

Analysis of main effects for different skill levels revealed significant differences. Advanced groups had greater wrist flexion amplitudes (32.79 ± 3.26°) than intermediate groups (26.17 ± 2.13°). At dart release, advanced groups had smaller elbow supination angle (26.94 ± 9.01°) and greater wrist palmar flexion angular velocity (1509 ± 166.9°/s) compared to intermediate groups (angle: 38.19 ± 10.24°; velocity: 1261 ± 241.4°/s) (Table 7).

DISCUSSION

The aim of the study was to identify the biomechanical characteristics of upper limb joint kinematics in accurate throws at vertical targets by comparing advanced and intermediate groups. At first, this study compares the difference of the throwing success rate between two groups. The result showed that the advanced group was significantly better than those of the intermediate group. The success rate of advanced group was similar to that of the expert or skilled dart players in previous dart throwing research (Nasu et al., 2014; Tran et al., 2019). This indicates that the participants were successfully divided into two groups of different abilities in this study.

This study investigated the interaction between various vertical targets and groups of different skill levels. The results unveiled a significant interplay between the targets and skill levels concerning the angular velocity of shoulder internal rotation. Specifically, the analysis of simple main effects indicated a notable increase in the angular velocity of shoulder internal rotation among participants with intermediate-level skills when transitioning from a lower target to a higher one during dart throws. Conversely, this significant difference was not observed among participants with advanced-level skills. These findings suggest that the angular velocity of shoulder internal rotation may impact the accuracy of dart throws aimed at different targets. This underscores the importance of maintaining a consistent shoulder rotation as a primary goal for achieving accuracy in dart throws, particularly when targeting varying vertical positions.

Furthermore, this study has also revealed an interaction involving elbow supination velocity and the different abilities of the dart throwers. There was a significant increase observed in elbow supination velocity among the intermediate skill level groups when throwing darts from a higher target to a lower target. Presently, there is no existing research on throwing indicating that altering elbow supination velocity confers an advantage in controlling throws aimed at different vertical targets. Only one study documented substantial changes in forearm supination during reaching tasks. (Vandenberghe, Levin, De Schutter, Swinnen, & Jonkers, 2010). Our study strongly suggests that involving the elbow joint in the regulation of throws aimed at different target positions should be avoided. The participation of the elbow joint may not provide beneficial contributions and could, in fact, lead to an increased likelihood of errors.

When the main effect of the different targets was analysed, our results showed that the shoulder elevation angle and angle velocity play a major role at dart release. This phenomenon is similar to previous studies on overarm throwing (Watts et al., 2004). Interestingly, the angular velocity of shoulder horizontal abduction also significantly increased when the dart was thrown at the lower target to the higher target. These results indicated that when dart is throwed to different targets, shoulder control not only depended on fine-tune control in the sagittal plane, but also needs coordination in the lateral plane, which is different with the regulation of overarm or ball throwing.

This study demonstrated that there was significantly different joint kinematics between the advanced and intermediate groups. Although previous studies have shown that the angle of shoulder elevation was significantly lower in experts than novices during acceleration phase of dart throwing (Rezzoug et al., 2018), joint kinematics of shoulder was not significantly different between the advanced group and the intermediate group in the present study. This result implied that the intermediate group was able to improve the angle of shoulder elevation compared to novices.

In terms of elbow joint movement, our results indicated that the intermediate group exhibited a higher elbow supination angle at dart release than in the advanced group. These results are similar in flying disc throwing research in which elbow pronation during throwing for the skilled participants (Sasakawa & Sakurai, 2008). Moreover, water polo throwing studies have shown that an excessive supination angle could decrease ball release speed (Feltner & Nelson, 1996). The reason is that maintaining the elbow pronation position contributes to flexion velocity at wrist and thus to object release velocity. Therefore, an excessive supination angle may result in a lower wrist flexion velocity at release for the intermediate group. Even though in dart throwing maximal velocity is not the primary objective, elbow pronation can be a marker of advanced levels in dart throwing.

In terms of wrist joint movement, the advanced group exhibited significantly greater wrist flexion amplitude during ACC phase than the intermediate group. Additionally, the advanced group demonstrated higher wrist palmar flexion angular velocity at dart release. Prior research on expert and novice dart players revealed that experts exhibit larger non-muscular interaction torques at the wrist joint that may lead to swifter palmar flexion angular velocity during dart release (Rezzoug et al., 2018). This also means that the wrist joint will have a faster palmar flexion angular velocity for experts during dart release. Moreover, a recent dart study confirmed that an increased angular acceleration of wrist at release was correlated with relative throw performance (Tran et al., 2019). Furthermore, baseball throwing studies have shown that an increase in wrist flexion angular velocity during throwing did not lead to increased performance error while still maintaining a consistent range of wrist flexion during throwing and similar final wrist position at release timing (Debicki, Gribble, Watts, & Hore, 2004; Hirashima, Kudo, Watarai, & Ohtsuki, 2007). Thus, heightened palmar flexion angular velocity signifies a crucial trait for advanced dart throwers. Intermediate dart throwers aiming to improve should gradually relinquish rigid wrist control and increase wrist flexion angular velocity at dart release.

This study successfully found better joint kinematics characteristics of upper limb at release for groups of different ability levels. Moreover, this study is the first focusing on the kinematics of advanced and intermediate groups during a throwing task. Previous studies usually compared the differences in throwing movement between advanced level and novice players (Nasu et al., 2014; Rezzoug et al., 2018; Tran et al., 2019), and these studies have not been able to clearly guide the improvement methods of intermediate players. Therefore, this study explores the differences in throwing movements between advanced and intermediate players to help develop training strategies with players to improve their performance.

The limitation of this study was that the results of this study are aimed at relatively advanced and intermediate players, so the research results cannot be extended to novices. Moreover, the sample size for each group was relatively small, as the recruitment for this study focused exclusively on the top 50 players domestically, leading to insufficient participant numbers. This limitation may hinder the generalizability of the research findings. Additionally, another limitation of this study is the potential impact of the adhesive light markers attached to participants during the experiment on their throwing performance. The presence of these adhesive markers may alter participants' throwing movements, thereby affecting the accuracy of the experimental results.

CONCLUSION

In conclusion, the advanced and intermediate groups appeared to use different strategies of throwing control for throwing darts to different vertical targets. Notably, the angular velocity of shoulder internal rotation displayed a significant interaction between targets and skill levels. Elbow supination velocity also exhibited and interaction with the different target level, emphasizing its role in throwing to different target positions. The analysis revealed a significant increase in the angular velocity of shoulder internal rotation and a decrease in elbow supination velocity among participants with intermediate-level skills while shifting from a lower to a higher target during dart throws. However, this significant difference was not observed among participants with advanced-level skills.

Additionally, this study uniquely focused on differences between advanced and intermediate players, offering insights often absent from prior research. The advanced players can accuracy throw dart to different target keeping the same elbow pronation angle and generate a higher angular velocity of wrist palmar flexion during the release process. Our findings indicate that a release of wrist palmar flexion at release is a key performance indicator for accuracy dart throwing. The results of this study can provide a reference guide for dart or light weight throwing to improve the accuracy performance.

AUTHOR CONTRIBUTIONS

All authors discussed and formulated this study. Conceptualization, Tsung-Yu Huang and Wen-Tzu Tang. Formal analysis, Tsung-Yu Huang, Hsin Yang and Wen-Tzu Tang. Investigation, Tsung-Yu Huang and Wen-Tzu Tang. Data curation, Tsung-Yu Huang and Hsin Yang. Writing original draft preparation, Tsung-Yu Huang and Wen-Tzu Tang. Writing—review and editing, Joseph Hamill and Wen-Tzu Tang. Supervision, Joseph Hamill and Wen-Tzu Tang.

SUPPORTING AGENCIES

We gratefully acknowledge the Chinese Taipei Darts Federation (CTDF) for assistance with equipment and recruitment of study participants.

DISCLOSURE STATEMENT

No potential conflict of interest were reported by the authors.

REFERENCES

Button, Chris, MacLeod, Morven, Sanders, Ross, & Coleman, Simon. (2003). Examining Movement Variability in the Basketball Free-Throw Action at Different Skill Levels. Research quarterly for exercise and sport, 74, 257-269. https://doi.org/10.1080/02701367.2003.10609090

Davis, Leon. (2018). From a pub game to a sporting spectacle: the professionalisation of British Darts, 1970-1997. Sport in History, 38(4), 507-533. https://doi.org/10.1080/17460263.2018.1511462

Debicki, DB, Gribble, PL, Watts, S, & Hore, J. (2004). Kinematics of wrist joint flexion in overarm throws made by skilled subjects. Experimental brain research, 154(3), 382-394. https://doi.org/10.1007/s00221-003-1673-4

Dehghani, Mohammad, Montazeri, Zeinab, Givi, Hadi, Guerrero, Josep M, & Dhiman, Gaurav. (2020). Darts game optimizer: A new optimization technique based on darts game. International Journal of Intelligent Engineering and Systems, 13(5), 286-294. https://doi.org/10.22266/ijies2020.1031.26

Feltner, Michael E, & Nelson, September T. (1996). Three-dimensional kinematics of the throwing arm during the penalty throw in water polo. Journal of Applied Biomechanics, 12, 359-382. https://doi.org/10.1123/jab.12.3.359

Hirashima, Masaya, Kudo, Kazutoshi, & Ohtsuki, Tatsuyuki. (2003). Utilization and Compensation of Interaction Torques During Ball-Throwing Movements. Journal of neurophysiology, 89(4), 1784-1796. https://doi.org/10.1152/jn.00674.2002

Hirashima, Masaya, Kudo, Kazutoshi, Watarai, Koji, & Ohtsuki, Tatsuyuki. (2007). Control of 3D limb dynamics in unconstrained overarm throws of different speeds performed by skilled baseball players. Journal of neurophysiology, 97(1), 680-691. https://doi.org/10.1152/jn.00348.2006

Hirashima, Masaya, Ohgane, Kunishige, Kudo, Kazutoshi, Hase, Kazunori, & Ohtsuki, Tatsuyuki. (2003). Counteractive relationship between the interaction torque and muscle torque at the wrist is predestined in ball-throwing. Journal of neurophysiology, 90(3), 1449-1463. https://doi.org/10.1152/jn.00220.2003

Nasu, D., Matsuo, T., & Kadota, K. (2014). Two types of motor strategy for accurate dart throwing. PLoS One, 9(2), e88536. https://doi.org/10.1371/journal.pone.0088536

Rezzoug, Nasser, Hansen, Clint, Gorce, Philippe, & Isableu, Brice. (2018). Contribution of interaction torques during dart throwing: Differences between novices and experts. Human movement science, 57, 258-266. https://doi.org/10.1016/j.humov.2017.09.004

Sasakawa, Kei, & Sakurai, Shinji. (2008). Biomechanical analysis of the sidearm throwing motion for distance of a flying disc: A comparison of skilled and unskilled Ultimate players. Sports biomechanics, 7(3), 311-321. https://doi.org/10.1080/14763140802270936

Šenk, Miroslav, & Cheze, Laurence. (2006). Rotation sequence as an important factor in shoulder kinematics. Clinical biomechanics, 21, S3-S8. https://doi.org/10.1016/j.clinbiomech.2005.09.007

Tran, Bao Nguyen, Yano, Shiro, & Kondo, Toshiyuki. (2019). Coordination of human movements resulting in motor strategies exploited by skilled players during a throwing task. PLoS One, 14(10), e0223837. https://doi.org/10.1371/journal.pone.0223837

Vandenberghe, Annelies, Levin, Oron, De Schutter, Joris, Swinnen, Stephan, & Jonkers, Ilse. (2010). Three-dimensional reaching tasks: effect of reaching height and width on upper limb kinematics and muscle activity. Gait & posture, 32(4), 500-507. https://doi.org/10.1016/j.gaitpost.2010.07.009

Vasiljev, R, Rubin, P, Milosavljevic, S, & Vasiljev, I. (2017). Transfer of under-foot load and mechanisms of control in dart sports. children, 19(3), 235-242.

Vereijken, Beatrix, Emmerik, Richard EA van, Whiting, HTA, & Newell, Karl M. (1992). Free (z) ing degrees of freedom in skill acquisition. Journal of motor behavior, 24(1), 133-142. https://doi.org/10.1080/00222895.1992.9941608

Watts, Sherry, Pessotto, Ivan, & Hore, Jon. (2004). A simple rule for controlling overarm throws to different targets. Experimental brain research, 159(3), 329-339. https://doi.org/10.1007/s00221-004-1957-3

Wu, Ge, Van der Helm, Frans CT, Veeger, HEJ DirkJan, Makhsous, Mohsen, Van Roy, Peter, Anglin, Carolyn, . . . Wang, Xuguang. (2005). ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion-Part II: shoulder, elbow, wrist and hand. Journal of biomechanics, 38(5), 981-992. https://doi.org/10.1016/j.jbiomech.2004.05.042

Wunderlich, Fabian, Heuer, Herbert, Furley, Philip, & Memmert, Daniel. (2020). A serial-position curve in high-performance darts: The effect of visuomotor calibration on throwing accuracy. Psychological Research, 84(7), 2057-2064. https://doi.org/10.1007/s00426-019-01205-2