UPPER LIMB JOINT ANGLES DID NOT DISTINGUISH SUCCESS OF THROW FOR A PROFESSIONAL DARTS PLAYER: PILOT CASE STUDY

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The purpose of this study was to identify upper limb kinematic differences between successful and unsuccessful darts throwing performance. One male semi-professional darts player attended a single data collection session in a laboratory setting. The player threw darts targeting either static accuracy (n = 36) or dynamic accuracy (randomised target for each throw, n = 60). The upper limb joint angles of successful and unsuccessful throws were compared for both accuracy conditions. Comparing successful and unsuccessful throws, there were no joint angle differences (statistical parametric mapping analysis = 0% time different) for any joint angle tested under either static or dynamic accuracy conditions.

KEYWORDS: Accuracy, hit, miss, kinematics, direct kinematic modelling.

INTRODUCTION: Darts is a game requiring high levels of coordination and advanced motor control skills rather than gross speed or strength. Three-dimensional (3D) biomechanical analysis of the throwing action can provide more accurate and quantifiable measures than traditional coach observation or video recordings, potentially revealing technique issues that can be addressed with training interventions.

There exists little research investigating the biomechanics of darts throwing, perhaps due to the relatively recent growth in popularity and commercial viability. Existing biomechanical analyses tend to focus on expert versus novice comparisons. For example, expert darts throwers have demonstrated more control (less variability) during movement execution than novices (Obayashi et al., 2009; Schorer et al., 2012), with variables such as shoulder (glenohumeral) rotation and ulnar deviation (Rezzoug et al., 2018), and shoulder and elbow displacement (Obayashi et al., 2014) identified as sources of difference.

Existing methods (Lohse et al., 2010; Rezzoug et al., 2018) may not be representative of match conditions as they targeted the bullseye (50 points), rather than the triple 20 (T20) sector (60 points), which the highest scoring and most commonly targeted sector during standard competition. Additionally, there is little research investigating differences between a successful and an unsuccessful darts throw.

The purpose of this project was to expand our current biomechanical knowledge of the darts throwing movement through quantification of full body kinematics of a semi-professional darts competitor. The preliminary analysis, presented here, investigates 3D modelled throwing arm joint angles and aims to identify differences between successful and unsuccessful throws. The null hypothesis tested was that there would be no difference between successful and unsuccessful throw arm joint angles.

METHODS: The male darts player (50 years, 176.2 cm, 84.7 kg) attended a data collection session at the SPRINZ motion capture laboratory. The laboratory was outfitted to meet competition regulations, including the dart board, dart board mount height (172.7 cm ground to the

Figure 1: Laboratory set-up for recording darts throwing.

centre bullseye) and throw line (oche, 236 cm from the front of the board). The player had a full body marker set (Figure 1) attached to their skin. Ten minutes warmup and familiarisation were provided, with the player following his usual pre-competition routine. He mimicked match performance by throwing three darts in succession (a ‘walk’) before retrieving the darts and waiting 10-15 seconds (the time an opponent would take) before performing the next walk. Two conditions were tested: static accuracy, where the target was always the T20 sector, and dynamic accuracy, where the target sector was randomised but always a triple or a double sector (smaller targets than single score sectors). For this analysis, each throw was recorded simply as either successful (dart lands in the targeted sector) or unsuccessful. Ethical approval was granted by Auckland University of Technology Ethics Committee (application 18/50).
Data Capture: 3D kinematic marker data were collected by a nine-camera Vicon motion analysis system (Vicon Motion Systems Ltd., Oxford, UK; 250 Hz). Calibration consisted of: a static A-pose, elbow epicondyle pointer (x2), and functional elbow flexion-extension trials. Following calibration and an additional few minutes warm up, the player completed 12 walks of static (n_{throws} = 36) and 20 walks of dynamic accuracy (n_{throws} = 60).
Data Processing: The 3D marker trajectory data were processed initially in Vicon Nexus software (V2.6, Vicon Motion Systems Ltd.) and subsequently in MATLAB with custom scripts (Mathworks, MA, USA). Trajectories were filtered using a fourth-order Butterworth low-pass filter at a cutoff frequency (14 Hz) determined by residual analysis and visual inspection. Marker data were subsequently modelled as per Wells et al., 2018, with the addition of a functionally defined elbow flexion-extension (FE) axis of rotation (SCoRE/SARA, Vicon Motion Systems Ltd.). Time-varying throwing (right) arm joint angles were output for the shoulder (FE, abduction-adduction (AA) and longitudinal rotation), elbow (FE), forearm (pronation-supination (PS)), and wrist (FE and AA). From the elbow FE data, peak flexion and the subsequent peak extension events were identified for each individual throw, and the duration of the extension movement (peak flexion to peak extension) calculated. The 0.5 seconds preceding and 0.5 seconds proceeding each peak flexion event was isolated as the period of interest, and data for all time-varying joint angles from these periods were extracted and normalised to 101 data points. Time-varying joint angles from successful throws were compared with corresponding data from unsuccessful throws for both static and dynamic accuracy conditions using statistical parametric mapping (SPM, Pataky et al., 2013). Peak elbow flexion and extension angles, and extension movement time from successful and unsuccessful throws for each condition, were compared with a two-sample t-test with effect sizes (Cohen’s *d*) assessed using criteria of trivial <0.2, small 0.2-0.49, moderate 0.5-0.79, large >0.8.

RESULTS: An unsuccessful throw was the most common outcome for both static (36 total throws, 8 successful (22%), 28 unsuccessful (78%)) and dynamic (60 total throws, 10 successful (17%), 50 unsuccessful (83%)) accuracy conditions. Comparing successful and unsuccessful throws, there were no joint angles differences (SPM analysis 0% time difference) for any joint angle tested in either condition (Figure 2). Elbow FE events and extension durations were similar for all conditions, with trivial effect sizes (<0.1) (Table 1).

Table 1: Descriptive and comparison statistics for the elbow FE events and extension duration.

Condition	**Outcome**	**Max. Flexion (mean ± *std. dev.*)**	**Max. Extension (mean ± *std. dev.*)**	**Extension Duration (mean ± *std. dev.*)**
Static (n = 36)	Successful (n = 8)	138.84 ±0.16	20.92 ±3.41	0.194 ±0.004
	Unsuccessful (n = 28)	138.68 ±0.29	21.48 ±4.02	0.192 ±0.005
	t-value (Cohen’s *d*)	t = 1.523 (*d* = 0.04)	t = -.358 (*d* = 0.01)	t = 0.820 (*d* = 0.02)
Dynamic (n = 60)	Successful (n = 10)	138.40 ±*0.37*	23.98 ±*3.02*	0.191 ±*0.005*
	Unsuccessful (n = 50)	138.59 ±*0.29*	22.44 ±*3.58*	0.192 ±*0.006*
	t-value (Cohen’s *d*)	t = -1.818 (*d* = -0.03)	t = 1.275 (*d* = 0.02)	t = -.515 (*d* = -0.01)

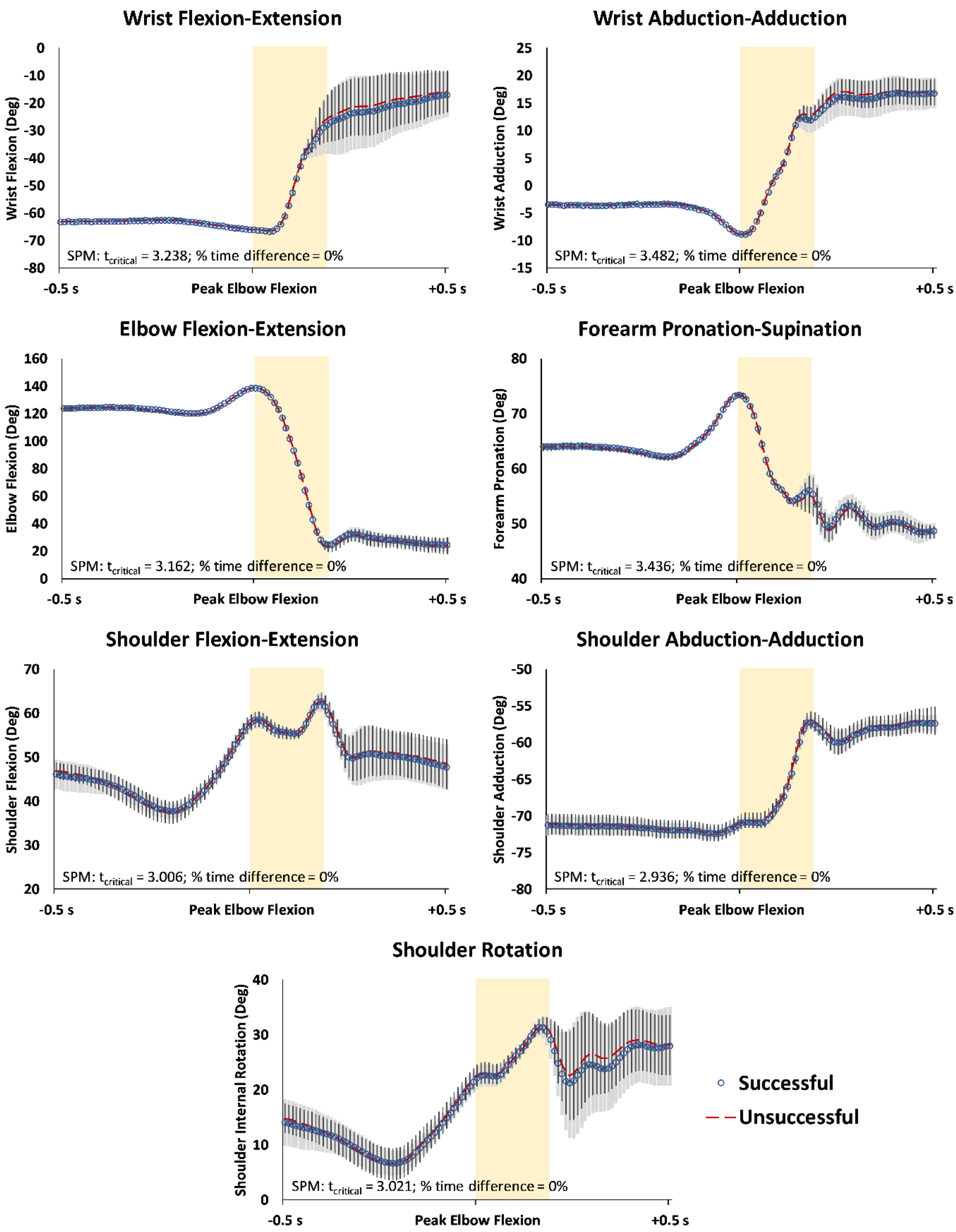

Figure 2: Time-varying joint angle data for the dynamic accuracy conditions. The shaded panel indicates the elbow extension movement (peak flexion to average peak extension). The SPM test results are inset for each comparison. Results from the static accuracy condition have been provided in the additional material.

DISCUSSION: This study tested the null hypothesis that throwing arm joint angles from unsuccessful darts throws would not be different from successful throws. This null hypothesis cannot be rejected, with no differences between successful and unsuccessful throws found for any of the joint angles investigated, for either accuracy condition tested. The consistency of joint angles across both conditions showcased the fine motor control required to be a competitive darts player.

Despite increased variation prior to, but particularly towards the end of and following the extension movement, the peak flexion values and extension movement duration demonstrated extremely high repeatability (138.62 ±0.3 degrees, 0.192 ±0.005 seconds respectively across all throws (n = 96)). Although low variation is to be expected in a case study with only one participant, the standard deviation is remarkably small and well below the accepted measurement error of such motion analysis. The player tested, who has undergone no formal training, has developed a highly refined, repeatable, throwing action. Peak elbow extension was marginally more variable in unsuccessful throws, though not to any statistical or meaningful magnitude (approximately 0.6 degrees, Table 1). Whilst throwing arm major joint angles are likely one component of a successful throw, this research demonstrates they are not the defining or singular factor. More in-depth analysis should provide greater context for the throwing arm. Obayashi et al. (2009) reported joint positions in space, particularly shoulder displacements, providing useful context for the throwing arm relative to the target, which was not discernible in the current analysis. The next stage of analysis may also explore factors further along the kinematic chain. The player in this study had indicated that they had previously undergone a stance change and was interested to know how variable the assumed stance was. Both joint global positions and lower limb kinematics, as well as other measures such as steadiness/balance, are planned for inclusion in upcoming analyses.

This research was limited in several respects. There were a small number of successful throws for each condition: this will be overcome with additional testing sessions increasing both the size of the dataset and the player familiarity with the laboratory setup. No finger kinematics were recorded: it is likely that the interaction of the fingers with the dart plays a substantial role in the success of the throw. Recording finger movement and dart interaction would be difficult, but a useful inclusion might be synchronised high-speed video to identify dart release.

The comparisons performed for this study were the first of a larger project to profile the full body kinematics of a darts player over a season of competition. Through the initial laboratory testing and consultation with the participant, coaches and other specialists, a training program is to be developed with the aim of improving competition performance. To our knowledge, no such biomechanically founded intervention plan has been proposed for a darts player.

CONCLUSION: No differences were found in throwing arm shoulder, elbow and wrist angles to differentiate successful and unsuccessful darts throws. This knowledge can be used by practitioners, players and coaches to encourage a holistic analysis approach, away from the throwing arm, for factors that potentially influence the success of a darts throw. This project is ongoing and will explore several of the expanded analysis options discussed.

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