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Biomechanical Analysis of Angular Velocity and Release Parameters in Javelin Throw Performance

Tariq K. Al-Dulaimi[1] , Ahmed F. Mahmoud[2]*

[1] College of Physical Education and Sports Sciences, Mustansiriyah University, Baghdad, Iraq

[2] Faculty of Physical Education, Alexandria University, Alexandria, Egypt

**Corresponding Author: ahmed1990g@gmail.com*

Abstract

Optimizing kinematic parameters during the terminal delivery phase is paramount to maximizing throwing distance in track and field throwing events. This study evaluated the relationship between trunk angular velocity, elbow extension speed, and javelin release parameters among competitive collegiate throwers. Twelve elite male javelin throwers (mean age: 21.4 ± 1.8 years, body mass: 84.6 ± 6.2 kg, height: 186.2 ± 4.5 cm) performed six maximal-effort throws under competition-standard conditions. Three-dimensional kinematic data were captured utilizing a synchronized four-camera high-speed motion capture system operating at 240 Hz. Release speed, release angle, attack angle, and joint angular velocities were computed and analyzed using Pearson product-moment correlation coefficients. The results revealed a significant positive correlation between peak forward trunk angular velocity and resultant release speed ($r = 0.81$, $p < 0.01$). Furthermore, elbow extension angular velocity demonstrated a substantial contribution to final launch momentum ($r = 0.74$, $p < 0.05$). Release angle exhibited an optimal performance window between 33° and 37°, with deviations exceeding 40° showing adverse aerodynamic drag penalties. These findings underline the critical importance of rotational torso acceleration and timed elbow extension mechanics over raw muscular force during delivery.

Keywords: Sports Biomechanics, Kinematics, Javelin Throw, Motion Analysis, Angular Velocity, Release Speed.

1. Introduction

The javelin throw represents one of the most technically demanding and explosive field disciplines in track and field athletics. Performance success, quantified by total horizontal distance, is governed predominantly by aerodynamic and projectile parameters established at the exact instant of release: release velocity, release angle, release height, and the angle of attack relative to environmental airflow.

Extensive biomechanical research confirms that release velocity accounts for more than 70% of performance variance. Achieving peak release velocity requires a proximal-to-distal kinetic chain sequence, where mechanical energy is sequentially generated by the lower limbs, transferred through

pelvic and trunk rotation, and accelerated via upper-extremity joint extension. Despite established kinematic models, the precise interplay between trunk angular deceleration and rapid elbow extension velocity remains a primary area of technical evaluation for training intervention. This study examines key 3D kinematic parameters governing delivery mechanics to provide evidence-based benchmarks for athletic coaching.

2. Materials and Methods

2.1 Participants

Twelve competitive male javelin throwers from national athletic training centers participated in the study (age: 21.4 ± 1.8 years; height: 186.2 ± 4.5 cm; body mass: 84.6 ± 6.2 kg; personal best performance: 68.4 ± 4.1 m). All participants had at least four years of competitive experience and were actively engaged in in-season competitive schedules without current musculoskeletal complaints.

2.2 Data Collection Protocol

Data acquisition took place at an outdoor certified athletics facility under neutral wind conditions (< 1.0 m/s). A calibrated 3D optoelectronic motion analysis framework incorporating four synchronized high-speed digital cameras (Qualisys, Gothenburg, Sweden) was deployed, operating at a sampling rate of 240 frames per second. Reflective markers (14 mm diameter) were affixed to anatomical landmarks adhering to standard biomechanical body segment conventions. Each athlete executed six recorded trials with international-standard competition javelins (800 g), following a personalized dynamic warm-up protocol.

2.3 Kinematic Variables and Data Processing

Raw coordinate data were digitized and filtered through a fourth-order Butterworth low-pass digital filter at a cut-off frequency of 12 Hz. The following metrics were extracted:

- **Release Velocity (m/s):** The linear velocity vector of the javelin center of mass at departure.
- **Release Angle (°):** The trajectory angle of the javelin velocity vector relative to the horizontal axis.
- **Trunk Angular Velocity (°/s):** Maximum forward sagittal angular velocity of the trunk segment prior to release.
- **Elbow Angular Velocity (°/s):** Peak extension angular velocity of the throwing arm.

2.4 Statistical Analysis

Data normality was evaluated using the Shapiro-Wilk test. Descriptive metrics are reported as means and standard deviations (SD). Pearson product-moment correlation analysis evaluated relationships between joint angular metrics and projectile release velocity. Statistical significance was designated at $p < 0.05$.

3. Results

The analysis demonstrated high kinematic consistency across top-tier trials. Table 1 outlines the measured release parameters and their statistical correlations with total throw distance.

Table 1: Kinematic Parameters and Correlation with Official Throw Distance (N = 12)

Biomechanical Metric	Mean ± SD	Correlation with Distance (r)	p-value
Release Velocity (m/s)	27.8 ± 1.4	0.92	< 0.001
Release Angle (°)	35.2 ± 2.1	0.61	< 0.05
Angle of Attack (°)	2.8 ± 1.2	-0.58	< 0.05
Trunk Angular Velocity (°/s)	620.4 ± 48.5	0.81	< 0.01
Elbow Angular Velocity (°/s)	1840.5 ± 112.3	0.74	< 0.01

Trunk forward rotation velocity strongly correlated with release velocity, confirming the vital contribution of rotational core stiffness in projectile acceleration. A moderate release angle ranging between 33° and 37° consistently yielded optimal aerodynamic carry distance.

4. Discussion

The empirical findings underscore the foundational role of segment coordination in elite throwing. Peak release speed was significantly dependent on the rapid braking action of the lead leg, which triggers an aggressive forward transfer of angular momentum into the trunk. When trunk rotation attains peak angular velocity, abrupt deceleration enables energy propagation into the shoulder and elbow segments, culminating in terminal hand release speeds exceeding 27 m/s.

Coaches must emphasize core rotational conditioning and ballistic plyometric exercises rather than isolated upper-body resistance training. Ensuring that the angle of attack remains minimized (between 0° and 3°) prevents excessive aerodynamic pitching moments during initial flight phases.

5. Conclusion

High-performance javelin throwing relies centrally on rapid trunk acceleration and precisely timed elbow extension angular velocities. Conditioning protocols should prioritize rotational power, rapid lead-leg braking mechanics, and aerodynamic release optimization within an angle band of 33°–37° to elevate competitive throwing output.

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