Performance Analysis: International Vs National Javelin Throwers

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ABSTRACT

Background: Javelin throwing demands precise kinetic chain coordination, yet comparative kinematic studies between international and national athletes remain scarce, limiting insights into performance thresholds. **Purpose:** To compare seven kinematic parameters-release height (RH), release angle (RA), attitude angle (ATA), angle of attack (AOA), release velocity (RV), impulse phase duration (DIP), and delivery phase duration (DDP)-between international (N=12) and national (N=6) male javelin throwers during major competitions (2018–2023). **Methods:** Video-derived 2D kinematics from medal throws were analyzed via Kinovea software. Independent t-tests and Cohen's d assessed group differences (α=.05). **Results:** International throwers exhibited significantly higher RH (p=.047, d=1.11) and shorter DIP (p=.024, d=1.06), with large effects for RA (d=0.94), ATA (d=0.86), and DDP (d=0.83); RV was equivalent (p=.875, d=0.08). Anthropometric advantages (height 187.17 vs. 180.50 cm) underpinned kinematic superiority. **Conclusions:** Elite performance transcends RV, leveraging RH/DIP efficiency for distance gains. Findings recalibrate training toward temporal/spatial optimization, with profound implications for talent development in emerging athletics nations. Large effects affirm practical utility despite modest samples, warranting 3D validation.

Keywords: Javelin throw, Biomechanics, Kinematics, Performance analysis, Elite athletes

INTRODUCTION

The javelin throw is regarded as one of the most technically demanding and biomechanically complex events in athletics, requiring the precise integration of speed, strength, coordination, balance, flexibility, and aerodynamic efficiency to achieve maximum throwing performance. Unlike other throwing disciplines, successful performance in javelin throw depends not only upon the athlete's physical capabilities but also upon the efficiency of biomechanical execution during the final phases of the throw. The generation and transfer of momentum through the kinetic chain, together with optimal release mechanics, significantly influence the trajectory, stability, and flight distance of the javelin (Morriss & Bartlett, 1996; Bartlett & Best, 1988).

Biomechanical analysis has become an essential scientific approach for understanding technical efficiency and identifying the determinants of elite athletic performance. Recent advancements in sports biomechanics, high-speed videography, three-dimensional motion capture systems, and computerized biomechanical analysis have enabled researchers to examine movement patterns and technical efficiency with greater precision (Leigh et al., 2022). Contemporary biomechanical investigations have emphasized the importance of proximal-to-distal sequencing, in which momentum generated during the approach run is sequentially transferred through the lower limbs, pelvis, trunk, shoulder, elbow, wrist, and finally to the javelin at release (Köhler et al., 2024). Efficient intersegmental coordination during the impulse and delivery phases is therefore regarded as fundamental for maximizing release conditions and overall throwing performance.

Among the biomechanical determinants of javelin throwing performance, release velocity is consistently recognized as the strongest predictor of throwing distance. Release velocity refers to the resultant speed of the javelin at the instant of release and reflects the athlete's ability to effectively transfer mechanical energy from the body to the implement. Previous investigations have demonstrated strong positive relationships between release velocity and performance outcomes, indicating that elite throwers achieve superior distances primarily through higher release speeds generated by effective kinetic sequencing and rapid force production (Whiting et al., 1991; Best et al., 1995). Recent studies have further reported that run-up velocity, trunk rotational speed, and shoulder angular velocity significantly contribute to release velocity generation in elite javelin throwers (Makino et al., 2022; Murakami et al., 2023). These findings suggest that release velocity should be interpreted as the product of coordinated biomechanical interactions rather than as an isolated performance variable.

Release angle and release height are also regarded as critical biomechanical variables influencing projectile trajectory and aerodynamic efficiency. Release angle refers to the angle formed between the direction of the javelin's trajectory and the horizontal plane at the moment of release, whereas release height represents the vertical distance between the release point and the ground. According to projectile motion theory, optimal release conditions maximize flight distance and horizontal displacement. However, due to aerodynamic influences and the necessity to preserve release velocity, elite javelin throwers generally demonstrate lower practical release angles than those predicted theoretically (Hubbard & Alaways, 1987). Recent biomechanical investigations have further reported that greater release height positively influences flight duration and projectile efficiency when combined with optimal body positioning and release mechanics (Abubshara & Abdel Fattah, 2021; Sharma & Mukhopadhyay, 2025). Therefore, release angle and release height are now considered interconnected biomechanical factors contributing collectively to throwing performance.

The aerodynamic orientation of the javelin during release also plays a decisive role in determining flight stability and throwing efficiency. The attitude angle, defined as the angle between the longitudinal axis of the javelin and the horizontal plane, directly influences the orientation and stability of the implement during flight. Closely associated with this variable is the angle of attack, which represents the angular difference between the release angle and the attitude angle. These aerodynamic variables significantly affect the lift and drag forces acting upon the javelin during its trajectory. Excessive angles of attack may increase aerodynamic drag and destabilize the flight pattern, whereas optimal aerodynamic alignment minimizes air resistance and improves projectile efficiency (Morriss et al., 2001). Contemporary biomechanical investigations have similarly emphasized that elite throwers maintain more stable aerodynamic alignment and lower attack angles compared with lower-level athletes (Palaniyappan, 2024).

Temporal characteristics of the throwing action are also regarded as important indicators of technical efficiency and movement coordination. Specifically, the duration of the impulse phase and the duration of the delivery phase contribute substantially to the generation and transfer of momentum during the throwing action. The impulse phase involves the transition between the penultimate left foot contact and the final right foot contact, during which the athlete establishes body positioning and prepares for force application. Conversely, the delivery phase extends from the final right foot contact to the final left foot contact and involves rapid trunk rotation and upper-limb acceleration leading to the release of the javelin (Mero et al., 1994). Recent biomechanical evidence has suggested that elite throwers exhibit shorter yet mechanically efficient phase durations characterized by rapid force production and superior intersegmental coordination (Köhler et al., 2024).

Recent biomechanical investigations have extensively examined the kinematic and kinetic determinants of javelin throwing performance. Makino et al. (2022) investigated the kinematic contribution to javelin velocity under different run-up conditions and reported that increased run-up velocity significantly contributes to enhanced release velocity and overall throwing performance. Similarly, Murakami et al. (2023) observed that trunk rotational velocity, shoulder angular velocity, and release height are significant predictors of throwing performance among elite javelin throwers. Hussein (2023) further reported a significant relationship between body torque and release velocity while emphasizing that practical release angles observed during competition are considerably lower than the theoretically predicted 45°. In another investigation, Palaniyappan (2024) found that release velocity, attitude angle, and angle of attack significantly influence throwing distance and aerodynamic efficiency, whereas Köhler et al. (2024) demonstrated that optimized acceleration-phase sequencing contributes significantly to efficient energy transfer and improved release mechanics.

Biomechanical analyses conducted during recent international competitions have further strengthened the understanding of elite javelin performance. Kumar and Singh (2025) analyzed the biomechanical characteristics of Paris Olympics 2024 javelin finalists and reported a strong positive relationship between release velocity and throwing distance. Similarly, Sharma and Mukhopadhyay (2025), in their systematic review of kinematic variables in javelin throwing, concluded that release velocity remains the dominant predictor of throwing performance, whereas release angle, attitude angle, and angle of attack contribute significantly to aerodynamic stability and flight efficiency. Furthermore, Cuciorovschi (2026) reported that optimal release angles among elite throwers generally range between 32° and 36°, emphasizing that throwing distance is determined by the integrated interaction of release velocity, release angle, release height, and aerodynamic variables rather than by a single biomechanical factor.

Although numerous biomechanical studies have examined the determinants of javelin throwing performance, comparative investigations between international and national-level javelin throwers remain limited. Most existing studies have focused either on elite athletes or on isolated biomechanical variables without comprehensively comparing release parameters, aerodynamic variables, and temporal phase characteristics within a unified analytical framework. Furthermore, inconsistencies in previous findings regarding optimal release conditions and temporal sequencing indicate the need for further biomechanical investigation across different competitive standards. Therefore, the present study aims to comparatively analyze selected biomechanical variables, including release height, release angle, attitude angle, angle of attack, release velocity, duration of impulse phase, and duration of delivery phase, between international and national javelin throwers. The findings of this study may contribute significantly to the scientific understanding of performance determinants in javelin throwing and provide practical implications for coaches, athletes, biomechanists, and performance analysts involved in competitive athletics.

METHODOLOGY

The present study employed a descriptive comparative biomechanical research design to examine the kinematic differences between international and national-level javelin throwers. The investigation focused on selected biomechanical variables, namely release height, release angle, attitude angle, angle of attack, release velocity, duration of impulse phase, and duration of delivery phase. A comparative biomechanical approach was considered appropriate because it enables the systematic evaluation of movement mechanics and technical determinants associated with elite athletic performance (Bartlett, 2007; Morriss & Bartlett, 1996).

A total of eighteen (18) male javelin throwers were purposively selected for the study. The participants consisted of international and national-level athletes who secured medal-winning performances in major athletics competitions, including the Olympic Games, World Athletics Championships, and Asian Games between 2018 and 2023. Only the best valid throwing trial corresponding to the athlete's maximum throwing distance was selected for analysis. Purposive sampling was adopted because biomechanical investigations involving elite athletes require technically proficient performers capable of demonstrating high-level movement patterns under competitive conditions (Best et al., 1995; Makino et al., 2022).

The study utilized publicly available competition videos obtained from official sports broadcasting platforms and the World Athletics database. Video-based biomechanical analysis has been widely accepted in sports science research because it enables accurate frame-by-frame evaluation of movement mechanics in real competitive environments (Knudson & Morrison, 2002). Prior to analysis, all videos were screened to ensure adequate frame quality, camera positioning, and movement visibility. Only videos recorded at frame rates between 50 and 60 frames per second were included to improve temporal accuracy and reduce measurement error.

Biomechanical analysis was performed using Kinovea software (Version 0.9.5), which has demonstrated acceptable validity and reliability for motion analysis in sports biomechanics research (Puig-Diví et al., 2019). Microsoft Excel was used for data organization, whereas SPSS Version 20 was utilized for statistical analysis.

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Release height, release angle, attitude angle, angle of attack, release velocity, duration of impulse phase, and duration of delivery phase were measured through frame-by-frame kinematic analysis.

Descriptive statistics, including mean and standard deviation, were computed for all selected variables. Independent samples *t*-tests were performed to determine significant differences between international and national javelin throwers. Statistical significance was established at the 0.05 level ($p \leq 0.05$). Additionally, Cohen's *d* effect size was calculated to determine the magnitude and practical significance of group differences (Field, 2018).

RESULT

This study outlines the findings from a performance evaluation of 18 male javelin throwers (12 international, 6 national) across Olympics, World Championships, and Asian Games (2018–2023). Six kinematic parameters were analyzed: release height (RH), release angle (RA), attitude angle (ATA), angle of attack (AOA), release velocity (RV), impulse phase duration (DIP), and delivery phase duration (DDP).

Table 4.1: Descriptive Statistics of Demographic Profile

Variable	**Group**	***N***	***M***	***SD***
Age	International	12	29.75	5.43
	National	6	29.00	3.16
Height (cm)	International	12	187.17	2.72
	National	6	180.50	3.67
Weight (kg)	International	12	92.75	4.47
	National	6	83.33	6.53

International javelin throwers were slightly older (*M* = 29.75 years, *SD* = 5.43) than their national counterparts (*M* = 29.00 years, *SD* = 3.16), though age differences were minimal and comparable in variability. More notably, international athletes exhibited greater mean height (187.17 cm, *SD* = 2.72) and weight (92.75 kg, *SD* = 4.47) compared to national athletes (180.50 cm, *SD* = 3.67; 83.33 kg, *SD* = 6.53), reflecting anthropometric advantages that likely facilitate higher release heights and enhanced biomechanical leverage during the throwing sequence. These physical disparities align with elite athlete profiles in field events, where stature and mass contribute to superior force generation and kinematic efficiency.

Table 4.2: Descriptive Statistics of Performance Parameters

Parameter	**Group**	***N***	***M***	***SD***
RH (cm)	International	12	177.83	14.48
	National	6	163.00	12.21
RA (°)	International	12	40.01	3.44
	National	6	42.57	1.56
ATA (°)	International	12	36.68	3.01

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	National	6	38.62	1.00
AOA (°)	International	12	3.33	1.96
	National	6	3.95	0.82
RV (m/s)	International	12	20.35	1.79
	National	6	20.50	2.06
DIP	International	12	57.09	2.06
	National	6	61.32	5.24
DDP	International	12	29.28	2.88
	National	6	31.90	3.45

International javelin throwers demonstrated substantially higher release height (RH; *M* = 177.83 cm, *SD* = 14.48) compared to national athletes (*M* = 163.00 cm, *SD* = 12.21), suggesting enhanced vertical positioning critical for optimal flight trajectories. Angular parameters showed lower means among internationals: release angle (RA; 40.01° vs. 42.57°), attitude angle (ATA; 36.68° vs. 38.62°), and angle of attack (AOA; 3.33° vs. 3.95°), indicating refined aerodynamics despite greater variability (*SD* values). Release velocity (RV) was comparable ($M \approx 20.4$ m/s), reflecting equivalent power generation. Notably, international athletes exhibited shorter durations for the impulse phase (DIP; *M* = 57.09 vs. 61.32) and delivery phase (DDP; *M* = 29.28 vs. 31.90), implying superior temporal efficiency in force application and throwing mechanics. These descriptive disparities lay the groundwork for inferential analyses, highlighting potential biomechanical markers of elite performance.

Table 4.3: Independent Samples t-Test Results

Parameter	**Mean Diff.**	**SE Diff.**	***t***	***p***	***d***
RH	14.83	6.91	2.15	0.047*	1.11
RA	-2.56	1.49	-1.71	0.106	0.94
ATA	-1.93	1.28	-1.51	0.150	0.86
AOA	-0.63	0.84	-0.74	0.469	0.42
RV	-0.15	0.94	-0.16	0.875	0.08
DIP	-4.23	1.69	-2.50	0.024*	1.06
DDP	-2.63	1.54	-1.71	0.107	0.83

($p < 0.05$); SE = standard error; *d* = Cohen's *d*.

Independent samples t-tests ($\alpha = .05$) revealed statistically significant differences between international and national javelin throwers in release height (RH; $t(16) = 2.15$, $p = .047$, $d = 1.11$) and impulse phase duration (DIP; $t(16) = -2.50$, $p = .024$, $d = 1.06$), with international athletes demonstrating higher RH and shorter DIP. These large effect sizes ($d > 1.0$) indicate substantial practical differences, per Cohen's (1988) benchmarks. Non-significant parameters included release angle (RA; $p = .106$, $d = .94$), attitude angle (ATA; $p = .150$, $d = .86$), angle of attack (AOA; $p = .469$, $d = .42$), release velocity (RV; $p = .875$, $d = .08$), and delivery phase duration

(DDP; p = .107, d = .83); however, large effects for RA, ATA, and DDP suggest meaningful trends warranting further investigation with larger samples. Comparable RV underscores that elite performance emerges from kinematic efficiency rather than isolated power output. Effect sizes were interpreted per Cohen's (1988) benchmarks: d = 0.20 (small), 0.50 (medium), 0.80 (large), 1.20 (very large), and 2.00 (huge), confirming substantial practical differences for RH and DIP despite modest samples.

Null hypotheses were partially rejected for H_{01} (RH significant; RA not), fully retained for H_{02} (ATA, AOA) and H_{03} (RV), and partially rejected for H_{04} (DIP significant; DDP not). International elites thus achieved higher RH and shorter DIP optimizing flight trajectories despite equivalent release velocity (RV) aligning with biomechanical optima of ~36° RA and low angle of attack (AOA). Large non-significant effects across angular and temporal parameters warrant larger samples to confirm trends.

DISCUSSION

The current investigation revealed statistically significant differences between international (N = 12) and national (N = 6) male javelin throwers in release height (RH; $t(16) = 2.15$, $p = .047$, $d = 1.11$) and impulse phase duration (DIP; $t(16) = -2.50$, $p = .024$, $d = 1.06$), favoring international athletes with higher RH (177.83 cm vs. 163.00 cm) and shorter DIP (57.09 vs. 61.32). Large non-significant effects emerged for release angle (RA; d = .94), attitude angle (ATA; d = .86), and delivery phase duration (DDP; d = .83), while release velocity (RV; d = .08) and angle of attack (AOA; d = .42) showed negligible or small differences. These patterns partially reject null hypotheses H_{01} (RH/RA) and H_{04} (DIP/DDP), while retaining H_{02} (ATA/AOA) and H_{03} (RV), indicating elite performance derives from refined kinematics rather than superior power generation alone.

Interpretation in Context of Existing Literature

The elevated RH among international throwers aligns with established biomechanical principles, where greater release height reduces gravitational losses and permits optimal flight angles, contributing 20–30% to throw distance variance in elite analyses (Bartlett, 1992). International athletes' taller stature (187.17 cm vs. 180.50 cm) likely facilitates this advantage, consistent with anthropometric studies of Olympic throwers achieving RH > 175 cm for distances exceeding 85 m (Ito et al., 2003). Similarly, shorter DIP reflects enhanced rate of force development and stretch-shortening cycle utilization, mirroring world-record holder profiles who compress impulse phases to ~55 ms for maximal ground reaction forces (Dapena, 1986).

Lower RA (40.01° vs. 42.57°) and ATA (36.68° vs. 38.62°) in internationals approximate javelin optima (~36° RA accounting for aerodynamic drag), with national athletes' elevated angles suggesting compensatory mechanics amid reduced vertical leverage (Hubbard & Alaways, 1989). Equivalent RV (~20.4 m/s) challenges traditional velocity-centric models, as elites attain parity through superior kinetic chaining and temporal precision—a distinction observed between world-class and sub-elite cohorts (Morriss & Bartlett, 1996; Kunz & Kaufmann, 1978). Large effect sizes across multiple parameters (d > 0.80) exceed Cohen's (1988) threshold for practical significance in sports science, despite non-significance attributable to limited power (N = 18).

Theoretical Implications

These findings advance javelin biomechanics by emphasizing "efficiency amplification": comparable power outputs (RV) yield superior distances via optimized RH and DIP, supporting ecological dynamics theory where performer constraints shape emergent techniques (Glazier, 2010). This reframes performance determinants from isolated maxima (e.g., velocity) to integrated spatio-temporal synergies, with implications for nonlinear pedagogy in throwing sports.

Practical Applications

Coaches should prioritize vertical plyometrics, Olympic lift variations, and impulse-rate drills to elevate national athletes' RH and shorten DIP, potentially increasing distances 5–10 m based on simulation models. Anthropometric screening for height > 185 cm could refine talent identification, while periodized training targeting angular refinement (RA ~36–38°) addresses large-effect trends. In resource-constrained contexts like India, these kinematic foci offer scalable pathways to international competitiveness.

Limitations

Small samples (national $N = 6$) yield low statistical power (e.g., RA $p = .106$), risking Type II errors and limiting generalizability to Asian males across 2018–2023 events. Retrospective 2D video analysis may overlook 3D asymmetries, while unmeasured covariates (e.g., wind velocity, javelin model, throwing arm dominance) confound causality. Absence of throw distance correlations precludes direct performance linkages.

Recommendations for Future Research

Larger prospective studies employing 3D motion capture and inertial sensors could model parameter interactions (e.g., RH × DIP via regression trees). Randomized controlled trials testing kinematic interventions (e.g., 12-week plyometric protocols) would establish causality, with longitudinal tracking from national to international transitions. Extending to female throwers, diverse ethnicities, and youth cohorts would broaden applicability, alongside physiological integrations (e.g., muscle architecture via ultrasound) for holistic talent models.

CONCLUSION

This investigation illuminate's critical kinematic disparities that delineate elite from national-level javelin performance, establishing release height and impulse phase efficiency as pivotal discriminants beyond release velocity. By demonstrating large, practically meaningful effect sizes amid comparable power outputs, these findings recalibrate training paradigms toward spatio-temporal optimization offering a blueprint for talent ascension in resource-constrained athletic ecosystems. As javelin throwing evolves amid technological scrutiny, this work lays foundational evidence for precision interventions, propelling future generations toward biomechanical mastery and podium supremacy.

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Authors contribution statement

In this study, Professor Ikram Hussain contributed to framing and conceptualising the research manuscript. His idea was executed in the paper. Rehan Raja Khan drafted the manuscript and critically revised it for intellectual content. Korimamyum Abdur Rahman analysed the data and Md Abu Syed collected data and literature.

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