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Biomechanical determinants of shot put performance: A correlational analysis of release height and velocity among elite Indian female athletes

Sandeep Kaur and Manmeet Gill

Abstract

Purpose: This study aimed to examine the relationship between key kinematic variables—height of release, horizontal velocity, and vertical velocity—and shot put performance in elite Indian female athletes.

Methods: A non-experimental, correlational research design was employed. Five elite female shot putters who represented India at the international level participated in the study. Each athlete performed ten rotational shot put attempts under standardized conditions. Motion was recorded using a CASIO EX-FH100 camera at 200 fps and analyzed with Quintic Coaching V- 35 software to obtain kinematic measurements. Pearson's product-moment correlation was used for statistical analysis.

Results: Significant positive correlations were observed between all three kinematic variables and shot put performance. Height of release ($M = 1.829$ m, $SD = 0.0143$) showed a strong correlation ($r = 0.731$, $p < .05$) with throwing distance. Horizontal velocity ($M = 8.757$ m/s, $SD = 0.711$) and vertical velocity ($M = 7.237$ m/s, $SD = 0.284$) exhibited extremely strong correlations with performance ($r = 0.960$ and $r = 0.974$, respectively, $p < .05$).

Conclusion: The findings confirm that release velocity is the most influential biomechanical determinant of shot put performance, followed by release height. These results highlight the importance of integrating technical refinement with strength and power training to optimize release parameters. Coaches and athletes should prioritize interventions that maximize release velocity while improving release height through technical adjustments and targeted strength training.

Keywords: Shot put, biomechanics, release height, horizontal velocity, vertical velocity, kinematic analysis

Introduction

Physical education and sports have entered a new era with the integration of sports sciences. Nations like the USA, Russia, Japan, Great Britain, and China dominate global sports due to the systematic application of scientific principles in athletic training and performance (Kumar & Rathore, 2015) ^[14]. The role of biomechanics has become critical in enhancing sports performance, preventing injuries, and optimizing human movement (Hall, 2018) ^[5].

Biomechanics in Sports

Biomechanics applies the laws of physics and mechanics to human movement, examining forces acting on the body and their effects (Hatze, 1974; Hall, 2018) ^[5, 7]. It provides a framework for understanding motion characteristics such as displacement, velocity, acceleration, and force application (Bartlett, 2007) ^[12]. By analyzing these elements, coaches and scientists can identify technique improvements that enhance performance and reduce injury risk (Knudson, 2009) ^[13].

Biomechanics serves multiple purposes.

- Improving performance efficiency through technical refinement.
- Preventing injuries via load distribution and equipment design.
- Developing specialized training programs tailored to athlete needs (Bahamonde, 2000) ^[11].

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Kinematic Analysis and Key Performance Factors

Kinematics, a branch of biomechanics, focuses on describing movement without reference to the forces causing it. It involves measuring linear and angular displacement, velocities, and accelerations of body segments (Robertson *et al.*, 2013) ^[20]. In sports like shot put, biomechanics evaluates critical parameters, particularly release velocity and height of release, as they significantly influence throwing distance (Linthorne, 2001; Hubbard *et al.*, 2001) ^[16, 10].

Studies demonstrate that while theoretical models suggest an optimal release angle of about 45°, elite athletes achieve greater results by prioritizing release speed over angle, maintaining slightly lower release angles for higher velocity (Hubbard *et al.*, 2007) ^[10]. Similarly, a greater height of release, influenced by athlete stature and technique, contributes to increased throw distance (Luhtanen & Komi, 1979) ^[17].

Key biomechanical principles affecting performance include:

- **Linear Velocity and Height of Release:** Higher release velocity and optimal height extend flight distance (Linthorne, 2001) ^[16].
- **Angular Momentum:** Rotational shot put techniques utilize angular momentum to generate higher release speeds compared to the glide technique (Bartonietz, 2000) ^[3].
- **Impulse-Momentum Relationship:** Applying force over a longer time during the delivery phase enhances shot velocity (Hamill & Knutzen, 2015) ^[6].
- **Kinematic Chain Principle:** Energy transfer from proximal to distal body segments improves efficiency (Putnam, 1993) ^[19].

Technological Integration

Modern biomechanics relies on tools such as high-speed videography, 3D motion capture, and computer-assisted modeling for quantitative analysis (Bahamonde, 2000; Yu & Hay, 2001) ^[1, 22]. These technologies allow accurate measurement of motion variables, including segmental velocities and release characteristics, aiding in technical corrections and performance optimization.

Qualitative analysis, using slow-motion video, remains a cost-effective method for coaches and athletes to review performance in real time. Quantitative analysis, however, offers precise data on variables like horizontal and vertical velocity, enabling detailed evaluations for elite athletes (Payton & Bartlett, 2008) ^[2].

Overall, biomechanics provides a scientific basis for performance enhancement in sports by analyzing and optimizing critical variables such as release velocity, height of release, and kinematic sequencing. Integration of technological tools further refines these assessments, making biomechanics indispensable for athletes and coaches seeking competitive advantage. As research advances, biomechanics will continue to play a vital role in sports science, bridging the gap between theory and practice for improved athletic outcomes.

Need for the Study

The need for this study arises from the growing demand for evidence-based approaches in sports performance optimization. In events such as shot put, critical biomechanical factors like release velocity, height of release, and coordinated energy transfer play a decisive role in determining success (Linthorne, 2001; Hubbard *et al.*, 2007) ^[16, 10]. Despite technological advancements, many athletes and

coaches continue to rely on traditional training methods, often neglecting these scientifically validated parameters. This gap highlights the necessity of research that translates biomechanical principles into practical applications for performance enhancement and injury prevention. By focusing on key performance variables and leveraging modern motion analysis techniques, this study seeks to provide actionable insights that support data-driven coaching and contribute to the advancement of sports science education and athletic excellence.

Hypotheses of Study

- There will be a significant relationship between height of release and Performance of elite Indian female shot putters.
- There will be a significant relationship between horizontal velocity of shot put and Performance of elite Indian female shot putters.
- There will be a significant relationship between vertical velocity of shot put and Performance of elite Indian female shot putters.

Methodology

Research Design: This research employed a non-experimental, correlational design to examine the rotational shot put technique among elite female athletes. The study focused on exploring the association between three kinematic variables—height of release (Hr), horizontal velocity (Hv), and vertical velocity (Vv)—and overall shot put performance. To ensure accurate measurement and data interpretation, motion capture technology combined with biomechanical analysis software was utilized.

Participants

The sample consisted of five elite female shot putters who had represented India at the international level. These athletes were purposively chosen based on prior competition performance. The participants' ages ranged from 24 to 34 years, with an average age of 23.6 years. All subjects were informed about the study and gave their consent prior to participation.

Study Variables

After an extensive review of relevant literature and consultation with subject matter experts, the following kinematic variables were selected:

- **Height of Release (Hr):** The vertical measurement of the shot above the ground at the instant of release.
- **Horizontal Velocity (Hv):** The shot's speed in the horizontal plane at release.
- **Vertical Velocity (Vv):** The shot's speed in the vertical plane at release.

Performance in shot put, expressed as the measured distance of each throw, served as the criterion measure for this investigation.

Filming Protocol

Performance recordings were captured using a CASIO EX-FH 100 digital video camera operating at 200 frames per second (fps). The camera was positioned 8 meters away from the athlete and aligned perpendicular to the direction of movement to obtain an accurate lateral view. Each athlete performed 10 trials of the rotational technique under standardized conditions, and every attempt was video

recorded. Footage was analyzed using Quintic Coaching V-35 software, a certified biomechanical analysis tool. The software allowed for video digitization, calibration, and extraction of relevant kinematic variables through advanced features such as auto-tracking markers, linear analysis modules, and graphical outputs.

Measurement Procedures

Horizontal and Vertical Velocity: After calibration, the linear analysis module of the software automatically computed horizontal and vertical velocities based on shot trajectory and body segment movements.

Height of Release: Using the auto-tracking functionality, the software calculated the shot's height above the ground at the precise moment of release.

Test Administration

Participants were instructed to execute the rotational shot put technique with maximum effort while maintaining natural technique. Before testing, athletes were familiarized with the filming and analysis procedures. Each subject completed 10 throws, and the best valid attempt was considered for analysis.

Data Reliability

To ensure precision and consistency, all instruments and software were standardized and calibrated prior to data collection. The CASIO EX-FH 100 camera (200 fps), measurement tools, and Quintic Coaching V-35 software were verified for accuracy by experts. A professional videographer

Horizontal Velocity and Performance

Table 2: Correlation between Horizontal Velocity and Performance in Female Shot Putters

Trial	Variable	Mean	Standard Deviation	Correlation (r)
50	Horizontal Velocity	8.757	0.7110	0.960**
50	Performance	16.985	0.9052	

Note: $r_{0.05}(48) = 0.278$; **Significant at 0.05 level

The mean horizontal velocity recorded was 8.757 m/s with a standard deviation of 0.7110. The computed correlation coefficient was $r = 0.960$, suggesting an extremely strong positive relationship between horizontal velocity and shot put performance. This relationship is significant at the 0.05 level.

Vertical Velocity and Performance

Table 3: Correlation between Vertical Velocity and Performance in Female Shot Putters

Trial	Variable	Mean	Standard Deviation	Correlation (r)
50	Vertical Velocity	7.237	0.2844	0.974**
50	Performance	16.985	0.9052	

Note: $r_{0.05}(48) = 0.278$; **Significant at 0.05 level

The mean vertical velocity was 7.237 m/s with a standard deviation of 0.2844. The correlation coefficient was $r = 0.974$, which represents a very strong positive correlation between vertical velocity and performance in shot put. This result is statistically significant at the 0.05 level.

Overall, the correlation analysis revealed that all three selected kinematic variables—height of release, horizontal velocity, and vertical velocity—show a significant positive relationship with shot put performance. Among these, vertical velocity ($r = 0.974$) exhibited the strongest association, followed by horizontal velocity ($r = 0.960$) and height of release ($r = 0.731$).

recorded all performances, and biomechanical assessments were conducted under the guidance of specialists. These steps ensured both the reliability and validity of the collected data.

Results

The data were collected from five elite Indian female shot putters who had represented India at the international level. Participants were selected using purposive sampling, and all subjects provided informed consent prior to data collection. To determine the relationship between selected kinematic variables and shot put performance, Karl Pearson's product-moment correlation coefficient was computed using IBM SPSS Statistics (Version 27). The findings for each variable are presented below.

Height of Release and Performance

Table 1: Correlation between Height of Release and Performance in Female Shot Putters

Trial	Variable	Mean	Standard Deviation	Correlation (r)
50	Height of Release	1.829	0.0143	0.731**
50	Performance	16.985	0.9052	

Note: $r_{0.05}(48) = 0.278$; **Significant at 0.05 level

The mean height of release was 1.829 meters with a standard deviation of 0.0143. The correlation coefficient between height of release and shot put performance was $r = 0.731$, indicating a strong positive relationship. This correlation is statistically significant at the 0.05 level.

Discussion

Height of Release and Shot Put Performance

Shot put performance is significantly influenced by biomechanical variables, and release height is among the most critical. Along with release velocity and projection angle, release height has consistently been identified as one of the major determinants of throwing distance (Linthorne, 2001; Hubbard *et al.*, 2007) [16, 10]. The current study reported a strong positive correlation between height of release and shot put performance ($r = 0.731$, $p < .05$), highlighting its relevance in the overall mechanics of elite I...

From a biomechanical perspective, release height affects the shot's trajectory and flight duration. According to projectile motion principles, a higher release point increases flight time, enabling the shot to cover a greater horizontal distance, even when velocity and angle remain constant (Hay, 1993) [8]. Hay emphasized that an elevated release point reduces reliance on steep projection angles, which often compromise release velocity. The average release height recorded in this study (1.829 m) was slightly below the international range for elite female shot putters (1.95-2.05 m) and well below the typical range for elite male throwers (2.1-2.3 m) (Bartonietz, 2000; Luhtanen & Komi, 1979) [3, 17]. These differences are largely attributable to anthropometric characteristics such as stature and limb length. However, despite these constraints, intra-group analysis shows that athletes with relatively higher release points consistently achieved better. Some athletes compensate for lower release heights by adjusting other variables, such as increasing release angle or emphasizing vertical velocity (Leigh & Yu, 2007) [15]. While these

adjustments can maintain performance, they may limit velocity potential. Therefore, targeted interventions to enhance release height—such as improving posture during the delivery phase, achieving full arm extension, and maximizing trunk rotation—remain crucial. Even small gains in release height can lead to measurable performance.

Release Velocities (Horizontal and Vertical) and Performance in Shot Put

The present study identified release velocity as the most critical biomechanical factor influencing shot put performance. Correlation results indicated extremely strong relationships between performance and both horizontal ($r = 0.960$) and vertical ($r = 0.974$) velocity components, corroborating prior research that velocity accounts for the majority of performance variance in throwing events (Hubbard, 1988; Linthorne, 2001) ^[9, 16]. The athletes demonstrated mean horizontal and vertical velocities of 8.757 m/s (SD = 0.711) and 7.237 m/s (SD = 0.284), respectively. These values represent a well-balanced distribution between horizontal propulsion and vertical lift, essential for optimizing projection trajectory. Velocity, being a vector quantity, depends on both magnitude and direction; achieving high resultant velocity while maintaining an optimal release angle (approximately 37°-40°) is vital for maximum distance (Linthorne, 2001) ^[16]. Past studies have shown that release velocity contributes to more than 80% of throw performance (Bartonietz, 2000) ^[3]. This dominance stems from the efficient transfer of mechanical energy through the kinetic chain, starting from the lower body and progressing through the trunk to the upper limbs (Judge, 2001) ^[11]. Inefficiencies in timing or technique at any segment reduce release speed. Strength and conditioning programs focused on developing explosive power have demonstrated significant improvements in release velocities. The strong correlations observed in this study suggest that velocity accounts for most of the performance variability among this elite sample. Consequently, training programs should emphasize enhancing velocity through both strength development and technical optimization. Furthermore, managing the balance between horizontal and vertical velocity components is critical. Excessive horizontal emphasis can limit flight time, while overly vertical emphasis compromises horizontal displacement. In conclusion, the findings of this study confirm that release height is a significant determinant of performance in shot put among elite Indian female athletes. However, improvements in this variable should be integrated with other biomechanical elements such as release velocity and angle to optimize performance holistically (Hubbard *et al.*, 2007) ^[10]. Further, the findings confirm that release velocity surpasses other kinematic variables in predicting shot put performance. Coaches should prioritize interventions that enhance both the magnitude and directional control of velocity. This approach, combined with strategies for maximizing height and refining projection angle, aligns with existing biomechanical evidence and offers a clear pathway for improving competitive outcomes.

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