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Biomechanical Contributions to the Precision of the Backhand High Serve in Competitive Squash

Dr. Ehab Saber Ismail

Professor, Faculty of Sports Sciences, Zagazig University

ehabsaber182@gmail.com

Abstract:

This study aimed to investigate the contribution of specific kinematic indicators to the accuracy of the backhand high serve in squash among elite U-19 players. Using a descriptive approach combined with 2D biomechanical video analysis, ten successful serve trials performed by five nationally ranked players were recorded and analyzed with high-speed cameras and Simi Motion software. The research focused on the moment of impact, examining variables such as segmental velocities of the racket, limbs, and trunk to determine their predictive power on serve accuracy.

The regression analysis revealed that the vertical velocity of the racket's midsection, the vertical velocity of the right leg, and the velocities of the elbow, left knee, and right shoulder significantly contributed to serve accuracy, with contribution rates exceeding 55% up to 96%. These findings provide novel insights into the biomechanical determinants of a critical squash skill, highlighting the importance of coordinated lower and upper body mechanics. The study bridges a gap in performance analysis within racket sports and offers practical implications for coaches aiming to refine technical execution and serve strategy in competitive settings.

Keywords: Backhand High Serve, Competitive Squash, kinematic indicators, kinetic chain coordination.

Introduction:

In recent years, squash has witnessed remarkable growth in Egypt, driven by disciplined and systematic training programs. This surge has propelled many Egyptian players to the top international rankings. Despite this success, certain technical skills remain challenging to teach and refine, largely due to the limited application of scientific methods—particularly biomechanical analysis—in the coaching process. Squash continues to attract a significant number of young participants, yet scientific research on its motor patterns and skill mechanics has not kept pace. This gap is critical, given that squash demands a diverse range of physical attributes such as anticipatory movement, rapid direction changes, and dynamic coordination under high-speed conditions.

Biomechanics, as a branch of movement science, plays a pivotal role in decoding complex athletic performances and enhancing them through detailed motion analysis. Its application in squash offers promising avenues to optimize technical skills like the high backhand serve, which requires precision, timing, and fluid kinematic chains. Effective performance depends on the integration of joint angles, segmental velocities, and coordinated muscle actions, particularly in the upper body. Understanding these kinetic and kinematic interactions not only improves training efficiency but also enables athletes to reach higher levels of execution by simulating and predicting optimal movement strategies through mathematical modeling and mechanical analysis.

The high backhand serve in squash is a complex offensive skill that demands precise coordination of multiple body segments executed swiftly in a short time frame. Despite its tactical value in controlling the central area of the court and securing direct points, this skill remains underdeveloped among many players—particularly juniors—due to the lack of comprehensive biomechanical understanding. Successful execution requires synchronizing lower and upper body movements to deliver the ball accurately toward specific zones in the front wall. However, mastering this serve is especially challenging because it involves turning away from the opponent and rapidly repositioning to regain control, increasing the likelihood of technical errors or loss of strategic advantage.

Although significant technological advancements have been made in motion capture and biomechanical analysis, racket sports like squash have not received adequate attention in studying the underlying kinematic patterns responsible for skill execution. This gap is particularly evident in the high backhand serve, which lacks thorough technical and mechanical breakdowns that could support skill acquisition and coaching strategies. Understanding how specific kinematic indicators contribute to serve accuracy is essential for optimizing performance. The current research seeks to address this gap by analyzing the mechanical contributors to this underexplored skill, providing a scientific foundation to support training interventions aimed at improving precision and technical execution.

Despite the widespread popularity of squash and its physical demands, detailed biomechanical studies focusing on skill-specific kinematic indicators remain limited. As observed by Kellis and Katis (2019), many performance-limiting factors in racket sports arise from a lack of understanding of the specific biomechanical sequences involved in complex skills such as the backhand serve. This aligns with the current study's rationale (page 4), which seeks to bridge the knowledge gap by quantifying joint contributions during key performance phases, thereby supporting both technical coaching and performance modeling.

One of the key challenges in performance analysis in squash is the scarcity of quantitative data describing the movement mechanisms that contribute to serve precision, especially from the backhand stance. As noted by Carson and Collins (2020), the ability to link biomechanical variables with performance outcomes—such as ball placement accuracy—is essential for evidence-based skill development. The present study addresses this need (page 5) by employing a detailed kinematic regression model, allowing coaches and athletes to understand which variables most influence serve success.

Despite the global popularity of squash, biomechanical research targeting sport-specific skills like the backhand high serve remains limited. As highlighted by Reid, M., Whiteside, D., & Elliott, B. (2016), there is a pressing need for applied biomechanical studies that translate directly into coaching strategies. This study addresses that gap by offering a detailed kinematic breakdown of a complex skill that is underrepresented in empirical literature, particularly in the context of junior elite performance, thus fulfilling both a scientific and applied need in the sport.

The importance of understanding joint-specific kinematics during high-speed racket actions lies in its direct influence on shot accuracy and player performance. Escamilla and Andrews (2018) emphasized that precise biomechanical patterns, particularly during overhead and rotational movements, are critical for optimizing kinetic chain efficiency and accuracy in racket sports. These insights align with the current study's aim to examine the vertical and horizontal velocities of joints such as the elbow, shoulder, and knees during the backhand serve in squash, particularly during the moment of impact.

Supporting the significance of joint velocity control in skilled actions, Marshall et al. (2021) and Meleigy, and Saber, (2025) reported that in racket sports, the vertical acceleration of the upper limb during pre-impact phases plays a decisive role in the directional accuracy and ball placement. This supports the current study's findings (page 15), where the vertical velocity of the racket head and shoulder during the moment of collision were highly correlated with serve accuracy. Their results reinforce the necessity of biomechanically informed training programs for young elite players.

This study aims to investigate the kinematic indicators associated with the backhand high serve in squash and their relationship to ball placement accuracy. Specifically, it seeks to identify the extent to which these kinematic variables—measured at the moment of impact—contribute to the precision of the serve among elite junior players.

It was hypothesized that specific kinematic indicators measured during the moment of impact in the backhand high serve significantly contribute to the accuracy of ball placement in squash.

Materials and Methods:

Subjects:

The researcher employed a descriptive methodology using two-dimensional biomechanical analysis, relying on video-based motion capture and kinematic assessment via Simi Motion Analysis software. The sample was purposefully selected and consisted of five elite squash players ranked among the top eight nationally in the under-19 category. This ensured a high technical proficiency necessary for accurately performing the high backhand serve. Each athlete executed two trials, yielding a total of ten recorded serves analyzed and statistically processed.

Table (1): "Summary of Participant Characteristics and Training Background"

Variables	Measuring unit	$\ddot{x}$	M	SD	Skewness
Age	Year	19	18.67	0.58	-1.73
Height	cm	173	173.67	4.04	0.49
Weight	kg	73.50	74.63	2.87	1.18
Training age	Year	8	8.33	0.58	1.37

Study design:

The study utilized a Resta meter model: PE 3000 to measure height (to the nearest centimeter) and a calibrated medical scale to assess body weight in kilograms. The squash-specific equipment included a standard squash court, a regulation squash racket, and official squash balls.

Motion Analysis Equipment For biomechanical analysis, the researcher employed two *high-speed Fastec Imaging video cameras* (50–250 fps), each equipped with 64 GB SanDisk memory cards and mounted on tripods with built-in leveling tools. A 50×50 cm 2D calibration frame and electrical extensions were also used. All video data were processed using a high-performance computer and analyzed via the Simi Motion Analysis software.

Biomechanical Analysis Protocol The kinematic analysis of the backhand high serve was conducted in collaboration with the Sports Research and Consultation Center at the Faculty of Physical Education, Zagazig University. Simi Motion Analysis was selected due to its versatility—it allows multi-camera input (up to 10), supports both 2D and 3D motion tracking, and is widely adopted in global sports science laboratories. The analysis focused specifically on the moment of impact during the execution of the skill.

A pilot study was conducted on Saturday, July 12, 2024, at the squash court of Al-Hayat International Academy in New Cairo. The sample included two players outside the main study group. The primary objectives were to assess the suitability of the filming environment and data collection tools, determine optimal camera positioning, height, and angles, ensure appropriate lighting conditions, verify the visibility of anatomical markers during recording, identify potential logistical or technical challenges, and set up the calibration frame and field of view to define the most accurate camera locations.

The main experiment was conducted on Saturday, July 19, 2024, at 3:00 PM at the squash court of Al-Hayat International Academy in New Cairo. Two high-speed video cameras (125 fps) were used for motion capture: the first positioned perpendicular to the player at a distance of 4.5 meters and height of 90 cm to capture the upper limb, trunk, and lower limb movement during the swing phase; the second aligned with the front wall, 5.44 meters from the service box and 1.78 meters high, matching the height of the service line, to accurately track ball motion during the impact phase.

Data analysis:

Table (2): Regression Analysis of Biomechanical Indicators and Backhand Serve Accuracy at Impact

Biomechanical Indicators	Mean	Standard Error	F-Value	Constant	Regression Coefficient	Contribution (%)
Racket Midpoint Vy	-0.161	9.420	10.016	8.846	0.283	55.177
Right Leg Vy	0.000	8.213	11.931	5.821	-2078489.157	62.552
Right Elbow Vy	-0.465	6.296	4.395	2.863	966064.857	75.319
Left Knee Vx	0.440	5.694	4.669	2.016	-6154022.518	85.686
Right Shoulder Vy	0.246	5.750	3.839	1.791	-3513907.435	96.017

Indicator 1: Vertical Velocity of the Racket Midpoint, the results indicated that the vertical velocity of the midpoint of the racket had the highest contribution to the accuracy of the backhand high serve during the moment of impact, with a contribution rate of 55.177%. This suggests a strong positive relationship between this biomechanical variable and serve precision. The increased velocity in the downward swing allows for greater force transfer, extending the length of the kinetic chain, and reducing the degrees of freedom in the striking arm. As the midpoint velocity of the racket increases, the remaining time before impact decreases, enabling a more controlled and forceful strike. This observation aligns with findings that emphasize the role of elbow flexion and wrist pronation in producing racket speed during impact. The angular speed and acceleration of the upper limb joints play a critical role in both forehand and backhand techniques, as these determine the velocity of the ball post-impact.

Predictive Regression Equation: $\tilde{y} = 8.846 + (0.283 \times -0.161) = 8.800$

Indicator 2: Vertical Velocity of the Right Leg, The second most influential factor was the vertical velocity of the right leg, contributing **62.552%** to the accuracy of the serve. A strong positive correlation was observed, indicating that as the vertical speed of the leg increases, the control and direction of the ball also improve. During the backhand serve, players extend the right knee upward and forward, aligning the ball trajectory toward the upper front wall, targeting difficult zones for the opponent. This specific anatomical positioning enhances biomechanical leverage, improving directional accuracy. The movement reflects the concept of kinetic linkage, whereby force is transferred from the lower limbs through the trunk to the upper limbs. Research supports this by highlighting the relationship between limb motion and ball speed.

Predictive Regression Equation: $\tilde{y} = 5.821 + (5.132 \times -0.161) + (-2078489.157 \times 0.000) = 8.800$

Indicator 3: Vertical Velocity of the Right Elbow, the third factor in importance was the vertical velocity of the right elbow, with a contribution rate of **75.319%** to serve accuracy. The data showed a clear positive correlation, indicating that the higher the vertical speed of the elbow during the swing, the more accurate the strike. This can be attributed to the ability of the player to better time and position the racket for a precise shot. Technically, the elbow must rise during preparation to maximize the impact force. This enables the ball to rebound effectively from the front wall to the designated quadrant on the court. Prior studies have confirmed that the vertical velocity of the striking arm is critical in influencing the projectile speed at the point of contact.

Predictive Regression Equation: $\tilde{y} = 2.863 + (2.919 \times -0.161) + (966064.857 \times 0.000) + (-17.569 \times -0.465) = 8.800$

Indicator 4: Horizontal Velocity of the Left Knee, The fourth contributing factor was the horizontal velocity of the left knee, with a contribution percentage of **85.686%**. Interestingly, the results revealed an inverse relationship; as the horizontal movement of the left knee decreased, accuracy improved. Biomechanically, this indicates that stabilizing the left knee during the strike creates a second-class lever system—pivoting on the left foot, with resistance being body mass and force generated by the striking arm. This stability facilitates better energy transfer through the kinetic chain from the lower body to the trunk and finally to the striking arm. These findings are consistent with research that explains how limb positions and lever types influence angular velocity and impact effectiveness.

Predictive Regression Equation: $\tilde{y} = 2.016 + (8.003 \times -0.161) + (-6154022.518 \times 0.000) + (-63.065 \times -0.465) + (-73.899 \times 0.440) = 8.800$

Indicator 5: Vertical Velocity of the Right Shoulder, The fifth and most substantial contributor to serve accuracy was the vertical velocity of the right shoulder, with an exceptionally high contribution rate of 96.017%. A strong positive correlation was found, where increased downward movement of the shoulder enhanced the preparatory backswing and extended the available time for a precise strike. This biomechanical advantage allows players to control the racket head more effectively, increasing accuracy. The vertical acceleration of the striking arm enables the precise targeting of the ball toward the front wall zones. Studies support that the striking arm achieves the highest angular speed during the backswing, influencing the overall effectiveness of the serve.

Predictive Regression Equation: $\tilde{y} = 1.791 + (4.116 \times -0.161) + (-3513907.435 \times 0.000) + (-37.007 \times -0.465) + (-41.901 \times 0.440) + (10.017 \times 0.246) = 8.800$.

Discussion:

The application of biomechanical analysis in racket sports has increasingly become a cornerstone in understanding performance-related variables, particularly in high-speed skills such as serving. According to Bishop, C., Read, P., Chavda, S., & Turner, A. (2016), the use of kinematic indicators allows for a more precise interpretation of joint coordination and sequencing during complex motions like the squash backhand serve, thereby contributing significantly to skill refinement and performance consistency. This aligns closely with the objective of the current study, which focuses on dissecting the moment of impact through detailed motion analysis to improve serve accuracy.

Research in the field emphasizes that efficient skill execution is largely dependent on the dynamic interplay between lower and upper body segments. The findings of Gomez, M. A., Pérez, J., & Lames, M. (2019) highlighted, Meligy, & Ismaail (2025) how kinetic chain coordination—from foot positioning to racket acceleration—can influence ball trajectory and precision. This perspective supports the current study's investigation of segment-specific kinematic contributions (e.g., knee, elbow, shoulder velocities) to ball placement, reinforcing the significance of analyzing each biomechanical element in isolation and within the full movement chain.

The utilization of 2D and 3D motion capture systems in recent literature, such as the work of Haake, S. J., & Foster, L. I. (2020), Meligy, & Ismaail (2025) has proven essential in quantifying critical performance variables with high reliability. Their research demonstrated how high-speed video and software-based analysis can isolate critical moments like impact and follow-through phases to determine performance efficiency. These methodologies mirror the analytical framework adopted in this study, thereby affirming both the validity of the approach and the reliability of the resulting kinematic insights regarding serve precision in squash.

Understanding the biomechanical determinants of performance is vital for optimizing technical instruction and training progression. According to Sánchez, A., Martín, C., & Sanz, D. (2022), Meligy, Ismaail (2025), identifying key velocity vectors and joint contributions during racket-based movements enables coaches to refine training drills and feedback protocols. This study's focus on the precise kinematic indicators of the backhand high serve provides coaches and athletes with a data-driven foundation for enhancing serve accuracy and reducing biomechanical inefficiencies.

The current research contributes significantly to the evolving field of performance diagnostics in adolescent athletes. Tornero-Aguilera, J. F., & Clemente-Suárez, V. J. (2023) emphasize the importance of biomechanical profiling during developmental years, as these data can inform long-term athlete development models. By focusing on U-19 elite players, the study not only adds to the evidence base of youth performance analysis but also offers valuable insights into how early interventions targeting serve mechanics may yield long-term improvements in competitive outcomes.

Conclusions:

The vertical velocity of the racket midpoint emerged as a primary determinant of serve accuracy, indicating that the kinematic chain's distal segment (the racket head) plays a pivotal role in optimizing backhand high serve precision during the moment of impact.

The vertical movement of the right leg significantly contributed to serve accuracy, supporting the principle that lower limb kinetic initiation enhances upper-body force transmission and facilitates precise ball direction through effective ground reaction forces.

The vertical velocity of the right elbow was strongly correlated with serve accuracy, reflecting the critical function of mid-arm segment coordination in timing and spatial targeting during the execution phase of the serve.

An inverse relationship was observed between the horizontal velocity of the left knee and serve accuracy, suggesting that greater stability and minimized lateral movement in the supporting leg are essential for anchoring body alignment and ensuring directional control.

The vertical acceleration of the right shoulder showed the highest predictive contribution to accuracy, emphasizing the importance of shoulder segment motion in controlling racket path, increasing angular momentum, and extending the striking arc during the backhand serve.

Coaches and biomechanics specialists should prioritize the development of shoulder and elbow segment control in training programs, using video analysis and motion capture to fine-tune vertical velocities during the backhand high serve.

Technical drills should focus on enhancing lower-limb force generation, particularly the controlled vertical extension of the right leg, to improve energy transfer efficiency from the ground up through the kinetic chain.

Stability-based training protocols for the support leg (left knee in right-handed players) should be implemented to minimize unwanted horizontal motion and promote precise postural control during ball striking.

Kinematic feedback tools, including wearable motion sensors and real-time visual feedback systems, are recommended for young elite players to monitor and adjust joint angular velocities and movement trajectories during serving drills.

Future biomechanical research should expand on 3D motion analysis across multiple phases of squash serves, incorporating a wider range of anthropometric and neuromuscular factors to enhance predictive models for skill execution.

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