ORIGINAL ARTICLE

Effects of foot orientation on serve velocity and accuracy in tennis

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ABSTRACT

The tennis serve is a technically complex biomechanical process where ball velocity serves as a primary determinant of competitive success and point dominance. This study examined how foot orientation (X, Y, and Z axes) and service side (Deuce and Ad court) influence serve velocity and accuracy in competitive players (N = 60; 30 male, 30 female). Participants performed serves in each condition using a randomized design to determine the biomechanical efficiency of varying stances. Velocity was recorded via radar technology, and accuracy was assessed based on target box success rates. In the Deuce court, foot orientation significantly affected velocity, revealing a distinct hierarchy where the Z-axis (diagonal) produced higher speeds than the Y-axis (net post) or X-axis (baseline) orientations. Conversely, no significant differences occurred in the Ad court (p > .05), suggesting side-specific motor stabilization. ANOVA results showed that accuracy remained consistent across axes (\chi^2(2) = 0.968, p = .616) and sides (p = .738), confirming the Z-axis velocity advantage induced no speed-accuracy trade-off. These findings highlight the asymmetrical nature of serve kinematics, suggesting that optimizing foot orientation toward the Z-axis in the Deuce court enhances mechanical efficiency and speed without compromising precision.
Keywords: Biomechanics, Ball velocity, Serve side, Biomechanical asymmetry, Serve accuracy, Service stance.

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INTRODUCTION

Tennis is a complex sport encompassing many different techniques and tactics, and one of the game's most fundamental and decisive strokes is the serve. The serve is not only the initiator of the game but also the first offensive move that provides an advantage over the opponent. Therefore, executing the serve with the highest possible speed and accuracy directly impacts both a player's success in the game and their consistent performance (Amir and Saifuddin, 2018).

Ball speed is one of the most critical factors determining serve performance. Factors affecting ball speed include the player's physical build, range of motion, muscle strength, and racket speed during the stroke (Gelen et al., 2009). In addition, the player's height and the height at which the ball is thrown also play a decisive role in serve success (Reid et al., 2011). Factors determining tennis serve speed are based on the interaction of anthropometric characteristics, physical strength and endurance capacity, and technical elements. From an anthropometric perspective, a player's height (BH), arm length (AL), and body composition (e.g., body mass index, BMI) play a determining role in serve speed (Bonato et al., 2013; Söğüt, 2016; Vaverka and Cernosek, 2013). Physical strength parameters, especially maximal isometric strength (MIS), rate of force development (RFD), and upper body strength, are of critical importance in speed production, and the development of these attributes are considered as the main targets for improving serve performance (Baiget et al., 2016; Colomar et al., 2020). From a technical perspective, lower leg thrust, hip and trunk rotations, and upper arm extension and internal rotation movements are mandatory movement patterns for effective energy transfer and increasing ball speed (Davey et al., 2017). In addition, fatigue conditions such as competitive loads and match intensity can negatively affect serve speed and accuracy (Rota et al., 2013).

An effective first serve provides an advantage to the player by paving the way for direct point-winning "*ace*" shots or a weak return by the opponent. Indeed, the percentage of points won after a first serve has been reported to be in the range of 72–81% (Keller et al., 2021). In this context, advanced kinetic chain coordination is essential for a powerful and effective serve. The fundamental elements that determine the quality of the serve include coordination of muscle groups, joint movements, and segmental kinematics; these elements also shape the speed and accuracy of different serve types (flat, slice, kick) (Brito et al., 2024).

In the tennis serve, the sequence of movements called the kinetic chain begins with the lower extremities and continues with trunk and upper extremity rotations (Elliott et al., 2003). The transfer of linear and angular momentum from the legs to the trunk and from the arm to the racket along this chain determines both the speed and control of the shot (Bahamonde, 2000). While the critical role of angular momentum in server performance is frequently emphasized (Elliott, 2006; Reid et al., 2008), research specifically examining the impact of the lower extremities on this process is limited (Martin et al., 2013). At this point, it should be emphasized that the factors affecting serve performance are not limited to upper extremity movements; lower extremity kinematics and foot positions can also play important roles. Indeed, the way the foot contacts the ground during the serve is considered a decisive factor in both maintaining balance and the efficient operation of the kinetic chain. The positioning of the lead foot, in particular, can directly influence trunk rotation and the effectiveness of upper extremity movements.

Studies on tennis serve technique in the literature generally focus on upper extremity kinematics, whereas research on the role of foot position and lower extremity structure in server performance is quite limited (Ellenbecker and Cools, 2010; Kibler et al., 2008; Vodicka et al., 2016). Lower extremity injuries have been reported to occur in 31–67% of tennis players (Ölmez et al., 2022), necessitating further investigation of foot and lower extremity biomechanics in terms of serve performance.

In this context, the purpose of the current study was to examine the effect of the lead foot's position on the ground during the serve on serve speed and accuracy in tennis. In this respect, the research aims to fill a gap in the tennis biomechanics literature focused on the lower extremity and to offer new perspectives on improving tennis performance.

MATERIAL AND METHODS

Participants

Thirty actively licensed, right-handed competitive young tennis players (30 males, 30 females; age range: 16–20) registered with the Turkish Tennis Federation's I-KORT system participated voluntarily in the study. The Turkish Tennis Federation's I-KORT system is the federation's official information and transaction system that brings together all participants in the tennis world; tournament, players, referees, coaches, clubs on a single online platform. The sample size was determined using a preliminary power analysis to detect differences in serve speed and accuracy with 80% power and a significance level of .05. Participants had no history of acute or chronic injuries or medication use that could affect performance.

The study was conducted in accordance with the principles of the Declaration of Helsinki and approved by the local ethics committee. All participants or their legal guardians were informed about the purpose, procedures, and potential risks of the study and provided written informed consent.

Note: Participants were asked to refrain from intense training or alcohol/caffeine consumption for 24 hours prior to the test days to avoid environmental and individual factors affecting the study.

Measures

Serve speed

Serve speed was measured using a Bushnell Velocity Speed Gun radar. Makar et al. (2024) compared the Bushnell Velocity Speed Gun with the Stalker Pro II and found high dispersion between the devices, indicating that the Bushnell Velocity Speed Gun radar can be used effectively for education and scientific research, just like the Stalker Pro II. The radar was positioned approximately 2 m from the ball, aligned with the centre of the service box and the baseline. The device was factory-calibrated and validated before each test. Measurement accuracy was set at ±0.16–0.32 km/h (≈±0.1–0.2 mph), and all data were recorded in km/h.

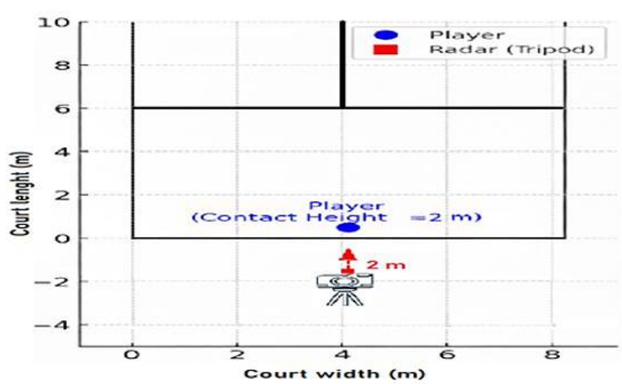


Figure 1. Schematic representation of radar gun positioning during tennis serve velocity measurement.

Accuracy
Whether serves landed in the target area was observed by three experienced tennis umpires. A consensus criterion was used for each serve. Serves that landed inside or on the service line were coded as "1," while those that landed outside were coded as "*0*." Only serves on which all three umpires agreed were included in the analysis.

Procedures
All tests were conducted on an indoor, hard-surface tennis court. Tests were conducted at the same time of day (9:00 AM–12:00 PM) to minimize the effects of biological rhythm and fatigue. Standard warm-up protocol was applied (general movements, mobilization with elastic band, a total of 16 services at a progressive speed: 8 at medium, 4 at high, 4 at maximum speed).Each participant served in three different foot orientations relative to the baseline:

- X-direction: foot parallel to the baseline.
- Y-direction: foot at a 45° angle to the baseline.
- Z-direction: foot perpendicular to the baseline, at a 90° angle.

Each participant served a total of 30 serves, 15 each from the deuce and ad courts. These 30 serves consisted of five serves for each position (X,Y,Z), with X,Y,Z on the ad court and X,Y,Z on the deuce court (Right X,Y,Z and Left X,Y,Z). The order of the trials was determined using a computer-based randomization algorithm to minimize learning and ordering effects.

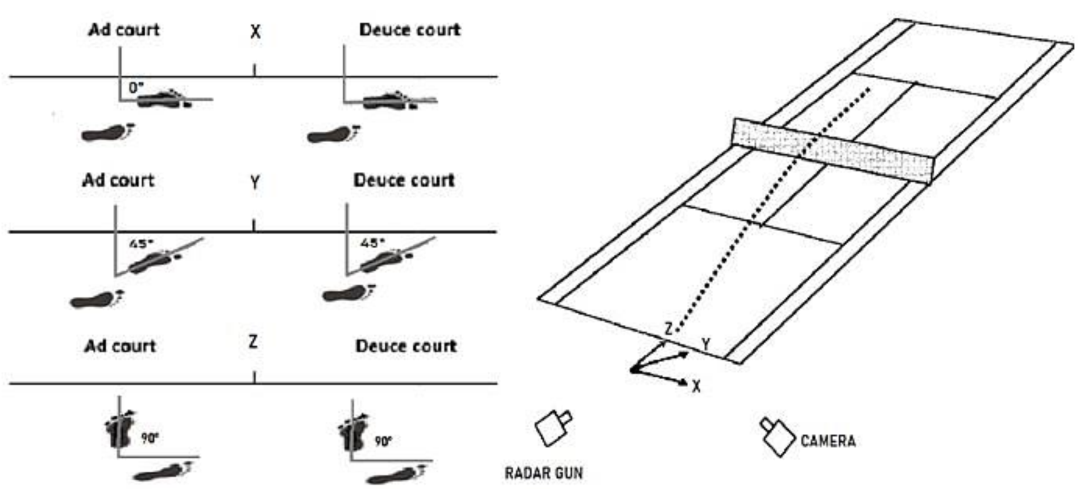


Figure 2. Schematic representation of tennis service foot positioning on the court.

4K, 60 fps video was recorded using an camera to verify the accuracy of the participants' foot positions. The camera was aligned with the baseline to clearly see the server's foot from the front; height, angle, and lighting conditions were standardized across all trials. The video was used only to verify foot positions; it was not used for speed or accuracy measurements.

A 30-second rest was given between each serve and a 2-minute rest was given between each set. During rest, fatigue level was recorded using the RPE (Borg 6–20 Scale); in cases of extreme fatigue, the trial was adjusted to repeat the trial.

Only straight serves were included in the study; players using slice or kick serves were excluded. Participants' individual straight serve performances were measured in a during test, and individual differences were controlled for in the analyses.

Figure 3. X-axis service performed with foot direction.

Figure 4. Y-axis service performed with foot direction.

Figure 5. Z-axis service performed with foot direction.

Statistical analysis

All statistical analyses were conducted using JASP (Version 0.18), setting the significance level at alpha = .05. Given the experimental design involving repeated measures (multiple serves per participant), Linear

Mixed Models (LMM) were employed for the continuous dependent variable, Serve Speed (km/h), and Generalized Linear Mixed Models (GLMM) for the dichotomous dependent variable, Serve Accuracy (Hit/Miss).

For the LMM (Speed), fixed effects included Gender, Axis, and Location, along with the *Location x Axis* interaction. For the GLMM (Accuracy), the model was specified with a Binomial distribution and a Logit link function. The fixed effects structure for the GLMM included Gender, Axis, and Location. Both models controlled for the variability attributable to individual participants by including Participant ID as a random intercept. Overall main and interaction effects were assessed via F-tests (LMM) and \chi^2-tests (GLMM). Subsequently, the magnitude and direction of all statistically significant findings were detailed using Estimated Marginal Means (EMMs), reported on the natural probability scale for clarity of interpretation.

RESULTS

Table 1. Descriptive statistics of serve speed (km/h) across levels of gender, serve location, and foot axis.

Serve	N	Mean	Std. Deviation
Female	900	82.34	13.34
Male	900	112.31	13.82
Right	900	96.40	20.34
Left	900	98.25	20-Ago
X	600	96.43	20.44
Y	600	97.64	19.87
Z	600	97.91	20.36

Note. N represents the total number of serves analysed for each category. Mean and Std. Deviation values are reported in kilometres per hour (km/h). Axis X, Y, and Z refer to the specific foot orientations tested during the serve.

N represents the total number of valid serves included in the analysis for each factor level. The dependent measure is Serve Speed, reported in kilometres per hour (km/h). The data illustrate that the mean speed for male athletes (112.31 \text{ km/h}) was considerably higher than for female athletes (82.34 \text{ km/h}). The sample sizes for Gender (Male/Female) and Location (Right/Left) are 900, while the sample size for each Foot Axis category (X, Y, Z) is 600.

Table 2. Linear Mixed Model (LMM) summary of fixed effects for serve speed (km/h). ANOVA summary.

Effect	df	F	*p*-Value
Gender	1,58.54	509.332	**<.001**
Location	1,1072.87	9.522	**.002**
Axis	2,1059.67	2.332	.098
Location axis	2,1585.49	10.440	**<.001**

Note. df values are calculated using Satterthwaite's method for degrees of freedom. The significant interaction (p < .001) between location and axis indicates that the effect of foot orientation on velocity differs depending on the service side.

The analysis of variance from the Linear Mixed Model (LMM) revealed that Gender had a highly significant main effect on serve speed (F(1, 58.64) = 509.332, $p < .001$), confirming that male athletes served significantly faster than female athletes (refer to Descriptive Statistics in Table 1).

A statistically significant main effect was also found for Location (F(1, 1072.87) = 9.522, $p = .002$). However, the main effect of Axis was not statistically significant (F(2, 1059.67) = 2.332, $p = .098$).

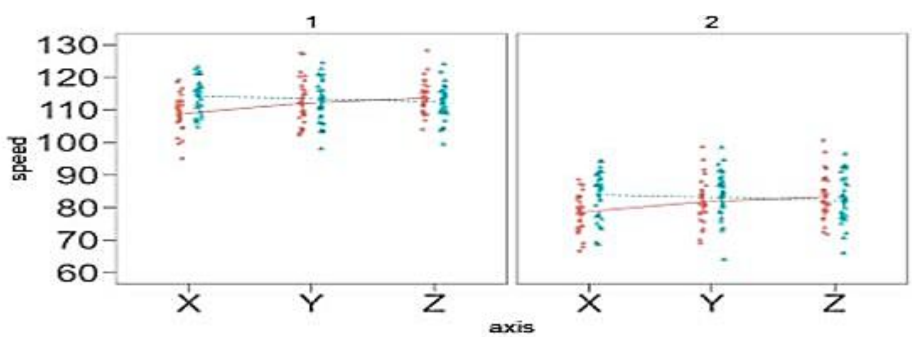
Most critically, a highly significant two-way interaction was observed between *Location x Axis* (F(2, 1585.49) = 10.440, *p* < .001). This significant interaction indicates that the effect of the foot axis position on serve speed is dependent on the side of the court from which the serve is executed. Further *post hoc* analysis is necessary to detail the direction of this interaction.

Table 3. Estimated Marginal Means (EMM) of serve speed and pairwise contrasts by serve location and foot axis.

Serve Location	Foot axis	EMM (km·h⁻¹)	SE	Comparison	Mean Difference	*p* - Value (Holm Adjusted)
Right (1)	X	93.71	0.894	X vs Y	-3.263	**.003***
	Y	96.98	0.970	X vs Z	-4.800	**.001***
	Z	98.51	0.940	Y vs Z	-1.537	.137
Left (2)	X	99.14	0.955	X vs Y	-2.427	.200
	Y	98.30	1.009	X vs Z	-2.977	.708
	Z	97.31	0.951	Y vs Z	-0.550	.725

Note. EMM = Estimated Marginal Means; SE = Standard Error. The p-values are adjusted for multiple comparisons using the Holm method to control the family-wise error rate. Asterisks (*) denote statistically significant differences (p < .05). Right (1) refers to the Deuce court and Left (2) refers to the Ad court.

Follow-up analysis of the significant *Location x Axis* interaction (F(2, 1585.49) = 10.440, *p* < .001) revealed distinct effects depending on the side of the court from which the serve was executed. Post hoc pairwise comparisons (Holm adjusted) showed that when serving from the Right (1) location, Axis X resulted in significantly lower speeds (93.71 \text{ km/h}) compared to both Axis Y (text{Mean Difference} = -3.263, *p* = .003) and Axis Z (\text{Mean Difference} = -4.800, *p* = .001), with no difference observed between Axis Y and Axis Z (*p* = .137). In contrast, when serving from the Left (2) location, the choice of foot axis did not produce any statistically significant differences in mean serve speed (all *p* > .200), indicating that the optimal foot placement strategy for maximizing velocity is specific to the right serving side.



Note: 1 = male, 2 = female, = right serve side, = left serve side.

Figure 6. Interaction of Foot orientation axis, serve side, and gender on serve velocity distribution.

The visual representation of the data provides compelling support for the proposed hypotheses concerning the differential influence of the Axis conditions based on Serve Side. While the dominant finding remains the highly significant main effect of Gender, with males (Panel 1) consistently exhibiting superior speed performance compared to females (Panel 2), the graph effectively illustrates the critical interaction effects. Specifically, the data confirms the hypothesis that the Axis condition significantly impacted speed performance for the right serve side ( ): the slight non-horizontal slope of the red trend lines, particularly noticeable in the male group, suggests a modulation of speed as a function of the axis change (X, Y, Z).

Conversely, the hypothesis regarding the absence of an Axis effect for the left serve side is visually confirmed by the predominantly flat and horizontal trend lines associated with the blue triangles, indicating that speed remained stable across the three axis conditions when serving from the left. This graphical distinction between the dynamic performance profile of the right serve and the stable profile of the left serve visually corroborates the statistically significant *Serve Side x Axis* interaction effect derived from the ANOVA.

Generalized linear mixed models

Table 4. ANOVA summary of service accuracy rates across foot orientation axis, gender, and court location.

Effect	df	Chi Sq.	*p* - Value
Axis	2	0.968	.616
Gender	1	4.797	.029
Location	1	0.112	.738

Note. 2 observations were removed due to missing values.

The results of the ANOVA analysis performed on the service accuracy rates revealed that the axes representing foot orientation did not have a statistically significant main effect on accuracy [\chi^2(2) = 0.968, *p* = .616]. This finding is of critical importance from a biomechanical point of view, as it proves that the speed hierarchy (Z > Y > X) observed on the right service side (deuce court) occurs without any loss of accuracy (speed-accuracy trade-off). While the literature emphasizes that service performance should be optimized as a whole, not only with the speed variable but also with the accuracy rate, the absence of an accuracy difference between the axes in our study confirms that the Z-axis orientation, which maximizes speed, provides mechanical efficiency without creating a technical risk. In addition, the lack of a significant effect of the service side (location) on accuracy [\chi^2(1) = 0.112, *p* = .738] indicates that this stability in accuracy rate is maintained on both sides of the court. In conclusion, for athletes aiming to increase serve speed without sacrificing accuracy, the preference for Z-axis orientation, especially on the right serve side, is considered a data-driven and reliable performance optimization strategy.

DISCUSSION

The tennis serve is widely recognized as one of the most vital and technically demanding biomechanical actions, primarily due to its role as the point of initiation and its decisive impact on point acquisition (Fett et al., 2020). At the core of a successful serve lies ball velocity, which emerges from a complex integration of the player's physical morphology, strength, and range of motion (ROM), alongside the intricate synchronization of joint and racquet speeds during execution (Soyal et al., 2018). While existing literature has extensively examined upper-body kinematics—specifically the angular momentum of the upper arm, forearm, and racquet, as well as proximal-to-distal segmental sequencing (Colomar et al., 2022; Martin et al., 2013)—the role of the lower extremities remains less understood. The transfer of momentum from ground reaction forces through the kinetic chain is arguably one of the most enigmatic biomechanical concepts in tennis (Bahamonde, 2000; Girard et al., 2010).

Historically, lower-limb research in tennis has concentrated on plantar pressure distribution (Girard et al., 2010) or the vertical positioning of the feet, categorized as "*foot-up*" and "*foot-back*" techniques (Brito et al., 2024; Girard et al., 2010). Although Martin et al. (2012) underscored the significance of foot placement in tactical scenarios like serve-and-volley play, scholarly work investigating the impact of foot orientation across different serve sides (deuce vs. ad court) on velocity remains sparse (Martin et al., 2013). In this context, the pioneering study by Fett and colleagues (2020) highlighted that switching serve sides could lead to distinct body and ball kinematics. Our findings corroborate the "*side-specific asymmetrical nature of serve* *kinematics*" proposed by Fett et al. (2020), as we observed a significant effect of axis orientation on velocity in the deuce court, whereas performance remained stable in the ad court.

The axis-dependent velocity fluctuations observed in the deuce court can be interpreted through the mechanical discrepancies identified by Fett et al. (2020). While they suggested that the lead foot should ideally point toward the right net post—a position corresponding to our Y-axis parameter—our data indicates a different hierarchy: the Z-axis produced the highest velocities, followed by the Y-axis, with the X-axis resulting in the lowest performance.

The increased axial sensitivity in the deuce court may be attributed to a more open stance and a larger upper-body ROM compared to the ad court (Fett et al., 2020). This asymmetry alters the management of braking forces developed by the front foot as the centre of mass shifts forward, thereby modifying the transmission of angular momentum (Bahamonde, 2015). The superiority of the Z-axis over the Y-axis suggests that this specific orientation facilitates a more efficient energy transfer by optimizing the interaction between the lower extremity segments and ground friction during the development of angular momentum. Furthermore, lower visual perception of the target area in the deuce court may influence player behaviour, leading to these observed velocity variances (Fett et al., 2020). While a more forward impact position generally benefits ball placement (Vaverka and Cernosek, 2013), the inherent mechanical asymmetry of the deuce side seems to hinder velocity maintenance across all axes, rendering alternative orientations like the Z-axis more dominant for power generation.

Conversely, the stability of velocity across all axes in the ad court serve suggests that the standard foot position (lead foot toward the right net post, back foot parallel to the baseline) provides a more balanced motor output on this side. As noted by Girard et al. (2010), the high pressures on the lateral-anterior part of the front foot are linked to knee extension, which directly enhances serve speed. Our results indicate that on the ad side, the kinetic chain operates more homogeneously and efficiently regardless of axis variations (Bahamonde, 2015; Girard et al., 2010).

Beyond velocity, this study also rigorously evaluated serve accuracy. The finding that ball-in rates did not significantly fluctuate across different axes is a critical observation. The absence of an "*accuracy-speed trade-off*" when utilizing the Z-axis proves that the velocity advantage gained does not come at the cost of precision. Consequently, to maximize speed without sacrificing accuracy in the deuce court, we recommend that players stabilize their foot placement along the Z-axis. This orientation appears to offer superior biomechanical efficiency compared to the Y-axis orientation suggested by Fett et al. (2020). Coaches and athletes should consider integrating Z-axis alignment as an optimization strategy within training regimens to manage the specific asymmetries of deuce-side serves.

In conclusion, while serve performance discourse often centres on the upper body, our study emphasizes the critical role of foot orientation and serve side. Given that high upper-body ROM and rotational forces in the deuce court are known risk factors for lower back injuries (Fett et al., 2020), implementing biomechanical adjustments in foot positioning is essential not only for performance standardization but also for long-term injury prevention (Fett et al., 2020; Girard et al., 2010).

CONCLUSIONS

This study investigated the influence of foot orientation and serve side on serve velocity and accuracy, highlighting a critical biomechanical gap in existing tennis literature. Our findings demonstrate that while serve velocity is fundamentally influenced by gender-based physiological factors, the mechanical efficiency of the serve is significantly modulated by the interaction between the serve side and the axis of foot orientation. Specifically, the deuce court serve exhibits a side-specific asymmetrical nature that makes velocity performance highly sensitive to axial changes. On this side, orienting the lead foot toward the Z-axis emerged as the most efficient strategy, yielding superior velocities compared to the traditionally recommended Y-axis (pointing toward the right net post) and the baseline-parallel X-axis, without any significant loss in accuracy.

In contrast, the ad court serve showed remarkable stability across all axis orientations, suggesting a more symmetrical and naturally efficient motor program on this side of the court. The absence of an "*accuracy-speed trade-off*" across all tested orientations indicates that biomechanical adjustments to foot angle can be utilized to maximize power without compromising the technical integrity of the serve.

From a practical perspective, these results provide coaches and elite athletes with a specific optimization strategy: stabilizing foot placement toward the Z-axis in the deuce court to enhance serve potency. Furthermore, considering that the deuce court requires higher upper-body range of motion and rotational forces, these biomechanical adjustments may also play a vital role in reducing the repetitive stress associated with lower back injuries. Future research should explore the longitudinal effects of axis-based training on performance consistency and its potential implications for different serve types, such as kick or slice serves, to further refine the biomechanical models of the tennis serve.

AUTHOR CONTRIBUTIONS

YDI – conceptualization of the study, research design, data collection, statistical analysis, interpretation of results, and drafting of the manuscript; SE – contribution to data analysis, interpretation of findings, and critical revision of the manuscript for important intellectual content; BF – contribution to methodology development, data acquisition, and review and editing of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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REFERENCES

Amir, N. (2018). Analysis of body position, angle and force in lawn tennis service accuracy. Journal of Physical Education and Sport, 18(3), 1692-1698. https://doi.org/10.7752/jpes.2018.03247

Bahamonde, R. E. (2000). Changes in angular momentum during the tennis serve. Journal of Sports Sciences, 18(8), 579-592. https://doi.org/10.1080/02640410050082297

Baiget, E., Corbi, F., Fuentes, J. P., & Fernández-Fernández, J. (2016). The relationship between maximum isometric strength and ball velocity in the tennis serve. Journal of Human Kinetics, 53(1), 63-71. https://doi.org/10.1515/hukin-2016-0028

Bonato, M., Maggioni, M., Rossi, C., Rampinini, S., Latorre, A., & Merati, G. (2015). Relationship between anthropometric or functional characteristics and maximal serve velocity in professional tennis players. Journal of Sports Medicine and Physical Fitness, 55(10), 1157-1165.

Brito, A. V., Fonseca, P., Costa, M. J., Cardoso, R., Santos, C. C., Fernandez-Fernandez, J., & Fernandes, R. J. (2024). The influence of kinematics on tennis serve speed: An in-depth analysis using Xsens MVN Biomech Link technology. Bioengineering, 11(10), 971. https://doi.org/10.3390/bioengineering11100971

Colomar, J., Baiget, E., & Corbi, F. (2020). Influence of strength, power, and muscular stiffness on stroke velocity in junior tennis players. Frontiers in Physiology, 11, 196. https://doi.org/10.3389/fphys.2020.00196

Colomar, J., Corbi, F., Brich, Q., & Baiget, E. (2022). Determinant physical factors of tennis serve velocity: A brief review. International Journal of Sports Physiology and Performance, 17(8), 1159-1169. https://doi.org/10.1123/ijspp.2022-0091

Davey, P. R., Thorpe, R. D., & Williams, C. (2002). Fatigue decreases skilled tennis performance. Journal of Sports Sciences, 20(4), 311-318. https://doi.org/10.1080/026404102753576080

Ellenbecker, T. S., & Cools, A. (2010). Rehabilitation of shoulder impingement syndrome and rotator cuff injuries: An evidence-based review. British Journal of Sports Medicine, 44(5), 319-327. https://doi.org/10.1136/bjsm.2009.058875

Elliott, B. (2006). Biomechanics and tennis. British Journal of Sports Medicine, 40(5), 392-396. https://doi.org/10.1136/bjsm.2005.023150

Elliott, B., Fleisig, G., Nicholls, R., & Escamilla, R. (2003). Technique effects on upper limb loading in the tennis serve. Journal of Science and Medicine in Sport, 6(1), 76-87. https://doi.org/10.1016/S1440-2440(03)80011-7

Fett, J., Ulbricht, A., & Ferrauti, A. (2020). Impact of physical performance and anthropometric characteristics on serve velocity in elite junior tennis players. Journal of Strength and Conditioning Research, 34(1), 192-202. https://doi.org/10.1519/JSC.0000000000002641

Gelen, E., Mengütay, S., & Karahan, M. (2009). Teniste servis performansını belirleyen fiziksel uygunluk ve biyomekaniksel faktörlerin incelenmesi. Uluslararası İnsan Bilimleri Dergisi, 6(2), 668.

Girard, O., Eicher, F., Micallef, J. P., & Millet, G. (2010). Plantar pressures in the tennis serve. Journal of sports sciences, 28(8), 873-880. https://doi.org/10.1080/02640411003792695

Keller, M., Kuhn, Y. A., Lüthy, F., & Taube, W. (2021). How to serve faster in tennis: The influence of an altered focus of attention and augmented feedback on service speed in elite players. The Journal of Strength & Conditioning Research, 35(4), 1119-1126. https://doi.org/10.1519/JSC.0000000000002899

Kibler, W. B., Sciascia, A. D., Uhl, T. L., Tambay, N., & Cunningham, T. (2008). Electromyographic analysis of specific exercises for scapular control in early phases of shoulder rehabilitation. The American Journal of Sports Medicine, 36(9), 1789-1798. https://doi.org/10.1177/0363546508316281

Makar, P., Silva, A. F., Silva, R. M., Janusiak, M., Smoter, M., & Clemente, F. M. (2024). The agreement between Bushnell and Stalker radar guns for measuring ball speed in throwing and kicking. Applied Sciences, 14(22), 10476. https://doi.org/10.3390/app142210476

Martin, C., Bideau, B., Nicolas, G., Delamarche, P., & Kulpa, R. (2012). How does the tennis serve technique influence the serve-and-volley?. Journal of sports sciences, 30(11), 1149-1156. https://doi.org/10.1080/02640414.2012.695079

Martin, C., Kulpa, R., Delamarche, P., & Bideau, B. (2013). Professional tennis players' serve: Correlation between segmental angular momentums and ball velocity. Sports Biomechanics, 12(1), 2-14. https://doi.org/10.1080/14763141.2012.734321

Rafael E. Bahamonde (2000) Changes in angular momentum during the tennis serve, Journal of Sports Sciences, 18:8, 579-592. https://doi.org/10.1080/02640410050082297

Reid, M., Elliott, B., & Alderson, J. (2008). Lower-limb coordination and shoulder joint mechanics in the tennis serve. Medicine & Science in Sports & Exercise, 40(2), 308-315. https://doi.org/10.1249/mss.0b013e31815c6d61

Reid, M., Whiteside, D., & Elliott, B. (2011). Hitting to different spots on the court: The ball kinematics of the professional tennis service. In Proceedings of the 29th International Conference on Biomechanics in Sports (Portuguese Journal of Sport Sciences, 11(Suppl. 2), pp. 849-852). Retrieved from [Accessed 2026. 09 February]: https://ojs.ub.uni-konstanz.de/cpa/article/view/4850

Rota, S., Morel, B., Saboul, D., Rogowski, I., & Hautier, C. (2014). Influence of fatigue on upper limb muscle activity and performance in tennis. Journal of Electromyography and Kinesiology, 24(1), 90-97. https://doi.org/10.1016/j.jelekin.2013.10.007

Soyal, M., Kaya, M., & Çelik, N. M. (2019). Examining the impact of musculus palmaris longus on serve speed and on certain motoric properties in tennis players. Pedagogics, psychology, medical-biological problems of physical training and sports, (4), 202-208. https://doi.org/10.15561/18189172.2019.0407

Söğüt, M. (2016). Ball Speed during the Tennis Serve in Relation to Skill Level and Body Height. Pamukkale Journal of Sport Sciences, 7(2). Retrieved from [Accessed 2026. 09 February]: https://hdl.handle.net/11511/75685

Vaverka, F., & Cernosek, M. (2013). Association between body height and serve speed in elite tennis players. Sports Biomechanics, 12(1), 30-37. https://doi.org/10.1080/14763141.2012.670664

Vodicka, T., Pieter, W., Reguli, Z., & Zvonar, M. (2016). Isokinetic strength of the wrist in male aikido athletes. Ido Movement for Culture, 16(2).