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Estrategia de servicio en el tenis profesional de dobles femenino - una perspectiva basada en datos
Serve strategy in professional women's doubles tennis - a data-driven perspective

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Abstract. This study aimed to identify the key variables that influence the effectiveness of the first serve in women's doubles matches using a deep learning training model. A total of 4939 first serves by 145 players from Billie Jean King Cup matches were classified according to their effectiveness. Data from the Hawk-Eye system were filtered and processed to obtain descriptive statistics of the spatio-temporal predictor variables and then to calculate the most important variables for first serve effectiveness. The angle of the serve as the feature that gained more relevance, along with the speed and distance from the bounce to the sidelines, regardless of the side from which the serve was made. The training model showed novel results, identifying that the values of the serve angle between 5.5º-8.7º increased the effectiveness from 22.2% to 48.5% on the Deuce side and from 17.3% to 45.7% on the Advantage side. These findings align with existing research on men's professional tennis singles and offer valuable insights into strategic and coaching approaches. The insights gathered from this study are poised to enhance training methodologies and match-day strategies, providing a strategic edge in serve selection during competitive play.
Keywords: racquet sports, machine learning, strategy, sport analytics, serve

Resumen. Este estudio tuvo como objetivo identificar las variables más determinantes que influyen en la efectividad del primer servicio en los partidos de dobles femenino utilizando un modelo de entrenamiento de aprendizaje profundo. Se clasificaron 4939 primeros servicios de 145 jugadoras según su efectividad, pertenecientes a partidos de la Copa *Billie Jean King*. Los datos del sistema de Ojo de Halcón fueron filtrados y procesados para obtener estadísticas descriptivas de las variables predictoras espacio-temporales y, posteriormente, se calcularon las variables más importantes para la efectividad del primer servicio. El ángulo del servicio fue la característica que obtuvo una mayor relevancia, junto con la velocidad y la distancia desde el bote de la pelota hasta las líneas laterales, independientemente del lado donde se ejecutó el servicio. El modelo de entrenamiento mostró que los valores del ángulo de servicio entre 5.5º-8.7º incrementaban la efectividad, pasando del 22.2% al 48.5% en el lado del Iguales, y del 17.3% al 45.7% en el lado de la Ventaja. Estos resultados no sólo se alinean con la investigación existente sobre el tenis profesional masculino tanto en la disciplina individual como la de dobles, sino que también ofrecen una valiosa orientación táctica y de entrenamiento. La información obtenida en este estudio está destinada a mejorar las metodologías de entrenamiento y las estrategias en el propio partido, proporcionando una ventaja estratégica en la selección del servicio durante la competición.
Palabras clave: deportes de raqueta, aprendizaje automático, estrategia, análisis deportivo, servicio

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Introduction

Tennis is an open skill sport in which, from a strategy perspective, players make tactical decisions based on their strengths and weaknesses, as well as those of their opponents. Additionally, other contextual variables, such as playing surface, type of balls, temperature, humidity or altitude, also significantly influence player performance (Fitzpatrick et al., 2019; Vaverka et al., 2018). In the quest to understand the critical factors that influence success in tennis, numerous studies have analysed players' match statistics (Crespo et al., 2015; Durán et al., 2022), as well as key performance indicators in junior and professional tennis players in different game situations (Jindo et al., 2022; Filipcic et al., 2021) and different types of playing surfaces (Fitzpatrick et al., 2019; Vaverka et al., 2018).

Similarly, an obvious lack of research can be observed in women's doubles, despite its relevance in team competitions such as the Billie Jean King Cup (BJKC). The BJKC, formerly known as the Fed Cup until 2020, is the most important global competition played by 110 national teams annually, which is the tennis World Cup for women. Created in 1963 by the ITF, it is the equivalent for women of the Davis Cup (BJKC, 2023). As aforementioned, research on this competition is substantially less common than in the men's events.

The serve is one of the key performance aspects in tennis, as it is a fundamental skill that plays a crucial role in the match outcome (Filipcic *et al. 2015; Grambow et al. 2022)*. In fact, points won with the second serve and points won with the return of the second serve have been identified by authors such as Reid, McMurtrie and Crespo (2010) as the most relevant variables of the game. In addition, it has been shown that players tend to improve their serving statistics as a tournament progress (Grambow et al., 2020). Also, players with a more effective serve achieve a higher percentage of points won on the second serve, show better performance in break point situations, and win more points and games when serving (Infantes et al., 2019). These findings highlight the importance of the serve in overall player performance.

Despite being the most decisive stroke in tennis today, the scarcity of studies dedicated to the serve in the women's game is evident (Sánchez-Pay et al., 2022). It has been demonstrated that both serving and returning are crucial elements in competition (Stănescu, 2016; Abidin & Ruslan, 2020). Furthermore, these elements significantly influence successive shots (Born, 2021). Authors such as Grambow et al. (2021), it is recommended that players prioritize the increase in the percentage of games and points won on serve,

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as well as perfecting aces to improve serving effectiveness. Other authors have explored biomechanical aspects (Whiteside et al., 2015) the kinematics of the first serve at different stages of training (Whiteside et al., 2013) or the relationship between serve speed and anthropometric parameters, ball impact and landing location (Baiget et al., 2023). Furthermore, studies have also analyzed how players' ranking can influence their performance (Sánchez-Alcaraz, 2018; Kovalchik et al., 2017)).

As per the serve in the doubles game, it has received considerably less attention from researchers than that of the singles. When comparing the serve efficiency between male and female professional players Carboch & Kočíb (2016) concluded that men won around 10% serve points more than women, and that to win a match they also needed to win more serve points than women. Kocib et al. (2020) tactically analysed the formations of serving and returning teams, and Avkhimovich (2023) investigated the order of servers in doubles and how this affects who should serve first. Martinez-Gallego et al. (2021c) demystified popular serving beliefs in doubles, concluding that the serving team's advantage is most notable on points of up to four shots, especially with new balls on clay, although this advantage diminishes on break points. Lastly, a study of Davis Cup doubles matches revealed that the effectiveness of the serve in doubles depends more on the angle and placement than on the speed of the serve (Vives et al., 2023).

In this context, other studies have focused on gender differences in the volley game in doubles, highlighting certain court coverage differences between men and women (Martínez-Gallego et al, 2021b), or the activity profile of players on different surfaces in doubles Grand Slam matches, resulting in short and intense points with a predominance of net play (Borderías et al., 2021). Finally, Borderías et al. (2023) analysed structural variables and the completion of points in women's doubles, concluding that taking the initiative and being aggressive in the game is beneficial for the point outcome.

From a technological perspective in terms of the tools used for match analysis, the use of tracking technologies in tennis, such as the Hawk-Eye (HE), has allowed different studies to use a large amount of data for the analysis of the singles game performance indicators. The serve has been analyzed in a myriad of studies (Loffing, 2009; Rioult et al., 2015; Wei et al., 2015; Mecheri, 2016; Whiteside and Reid (2017). For instance, Fitzpatrick et al. (2023) explored the different serve and return strategies used by male and female players at Wimbledon. Other studies have also investigated the different movement parameters, changes of direction and hitting dynamics of male and female players during matches (Wei et al., 2013; Reid and Duffield, 2014; Reid et al., 2016; Giles et al., 2020; Brandon et al., 2021; Wei et al., 2013; Meurs et al., 2021).

In doubles, HE data has been used to analyse how serve direction varies with server position. Vives et al. (2021) found that server position was a key factor in the direction of the first and second serves, affecting both serve efficiency and return anticipation. The differences in the characteristics of the serve in men's and women's doubles tennis have also been analysed in terms of its effectiveness and the directions used, and Martínez-Gallego et al. (2021a) concluded that men's teams are more effective than women's, especially in serves directed to areas far from the center of the serve box.

Despite the recognized importance of the serve in tennis and the numerous studies that have examined its various aspects in singles and the men's game, there is a significant lack of research specifically focused on women's doubles, particularly in high-level competitions such as the Billie Jean King Cup (BJKC). This gap in the scientific literature highlights the necessity for research that utilizes current technologies and analytical methods to explore serve dynamics and strategies in this discipline. Accordingly, this study aims to address this gap by identifying and analyzing the key variables that influence the effectiveness of the first serve in BJKC women's doubles matches.

Methods

Sample

A total of 4939 first serves was analysed from 65 women's doubles matches played during BJKC qualifying ties between 2011 and 2019. Our study featured the participation of 107 teams and 145 players from 23 different countries, with an average age of 25.81 $\pm$ 4.74 years.

Process

The data used in this study was obtained using the HE tracking system (Hawk-Eye Innovations Ltd., 2015). The HE tracking technology has passed rigorous ITF tests that have validated the accuracy and reliability of the system. A system of synchronized cameras is used to track the movement of the ball in real time. Each camera captures the position of the ball in its own plane. By knowing the position and orientation of each camera, the 3D position of the ball can be estimated by intersecting the trajectories defined by the cameras. This allows the three-dimensional coordinates of the ball to be determined accurately in space (Singh Bal & Dureja, 2012; Reid et al., 2016).

After acquiring data from the HE system, a template was developed using Microsoft Excel version 16.16.7 (Microsoft, Redmond, USA) to facilitate data processing and the calculation of targeted variables.

Target variables

The variables derived and analyzed in this study were:

- Court side: Side of the court from where the serve is played. This variable was used to divide the dataset and perform the analysis for each side of the court.
- Effectiveness:
  - Type 1: The point finishes with one shot.
  - Type 2: The point finishes with two shots.

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- Type 3: The point finishes with three shots.
- Type 4: The point finishes with four or more shots.

Input features

- Speed: Mean speed of the serve.
- Position: Position of the server when hitting the serve.
- Time: Time between ball impact and ball bounce.
- Speed loss: Loss of speed of the ball after its bounce.
- Impact Z: Height of the ball at impact.
- Net clearance: Height of the ball when passing over the net.
- d: Serve angle.
- b: Vertical projection angle.
- dL: Distance from ball bounce to the sideline of the serve box.
- Direction: Wide (W), Body (B) and T (Figure 1).

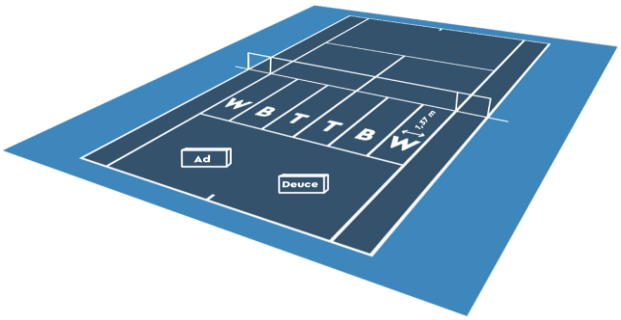

Figure 1. Serve direction

Data analysis

The Machine Learning methodology used in this study was used and validated in a previous study by Vives et al. (2023), using the following steps:

Predictive model: Training the deep learning model

This study compared AutoGluon and FastAI for tabular data analysis. Although AutoGluon offers outstanding tools, its lack of flexibility leading to the choice of FastAI. The implementation of AutoGluon was straightforward, while FastAI required more development, but provided flexibility.

A tabular model with 5 layers of feature size [256, 128, 128, 128, 128, 64] and LinBnDrop basic blocks were used. The loss function was Focal Loss Flat, and the Adam optimization algorithm (Kingma & Ba, 2015) was used. This work contributes to the understanding of tools for tabular data analysis.

Feature importance: Most important variable

The Feature Permutation Importance methodology emerges as a robust tool, facilitating the identification of features with predictive capability, irrespective of the employed model. This approach provides a valuable perspective for assessing the individual contribution of variables within the broader analytical framework (Kuhn & Johnson, 2013).

Feature importance algorithms were employed to identify variables with a substantial impact a predictive model, indicating the relative significance of each feature in making predictions. It is based on repeated permutations of the outcome vector to estimate the distribution of measured importance for each variable in a non-informative setting (Rajbahadur et al., 2022).

Probabilistic and statistical analysis: Values that maximize the probabilities

In the context of a study focused on maximizing serve effectiveness and understanding the impact of selected features on predicted target variables, a novel semi-automated algorithm based on classical statistics was developed.

The initial steps involved calculating a smooth probability distribution using the Kernel Density Estimation algorithm for each selected feature, along with statistical estimators such as Mean, Maximum Likelihood Estimation (MLE), and percentiles 5 and 95 for each type of effectiveness. Subsequently, values were identified by selecting areas on the plot with a higher density of points corresponding to the desired result (type 1) and a lower density of points for the undesired result (type 4). Statistical estimators played a crucial role in interpreting the probability distribution during this process.

Synthetic data-set generation: simulation based on the predictions on this dataset and analysis of effectiveness improvements

The final step was to create a synthetic dataset by applying the identified thresholds to the original dataset Through validation procedures, we made adjustments to improve the effectiveness rate. To further refine the dataset, any values outside the specified thresholds were replaced with random values within the acceptable range, creating a new synthetic dataset. We then used the previously trained deep learning model to make predictions on the synthetic dataset, calculating the final rates for effectiveness type 1 and effectiveness type 4.

The Effectiveness results using the original dataset and the new synthetic dataset with the recommended threshold values are shown in table 2. They show how the model trained on the original dataset impacts the effectiveness on the second dataset, increasing the overall probability on the synthetic dataset by 47.1%

Results

Descriptive statistics of the spatio-temporal predictor variables

Table 1 shows the descriptive statistics of the spatio-

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temporal predictor variables. As it can be seen in the results, the mean of the variable speed is higher in aces than in the rest of the serves, both on the Deuce side with 160.19 km/h and on the Advantage side with 165.90 km/h. This difference is also reflected in the d, being the angle greater in aces with an average of 5.99º on the Deuce side and 5.74º on the Advantage side. On the other hand, the dL was another of the variables that showed significant differences between the aces and the rest of the serves, being the shortest distance in aces regardless of the side. Regarding the rest of the variables, as can be seen, their means were quite similar on the Deuce and Advantage sides, both for the serves that were aces and for the rest of the first serves.

Table 1.
Descriptive statistics of the spatio-temporal predictor variables

	DEUCE				ADVANTAGE			
	Total (N=2615)		Aces (N=156)		Total (N=2324)		Aces (N=113)	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Speed (km/h)	154.14	13.63	160.19	15.69	155.88	13.72	165.90	13.64
Position (m)	2.03	0.73	1.96	0.79	2.03	0.82	1.82	0.89
Impact Z (m)	2.67	0.14	2.70	0.13	2.68	0.15	2.72	0.14
Net Clearance (m)	1.14	0.11	1.13	0.11	1.14	0.11	1.13	0.11
Time (s)	0.48	0.05	0.47	0.05	0.48	0.05	0.45	0.04
Speed loss (km/h)	7.80	1.20	7.76	3.28	7.85	1.14	7.50	2.83
Serve angle (deg.)	3.59	1.91	5.99	1.64	3.63	1.74	5.74	1.56
Vertical projection angle (deg.)	9.05	0.61	9.07	0.56	9.02	0.64	9.05	0.55
dL (m)	1.01	0.54	0.39	0.37	0.99	0.56	0.40	0.47

Calculation of the most relevant variables

The next step was the calculation of the serve variables that were most important for type 1 effectiveness. Figure 2 shows the mean values indicating the average impact on the model outputs for each variable on the Deuce side, the Advantage side and both sides respectively. As it can be seen, the most important variables were d, speed and dL to the line irrespective of the side where the serve was played.

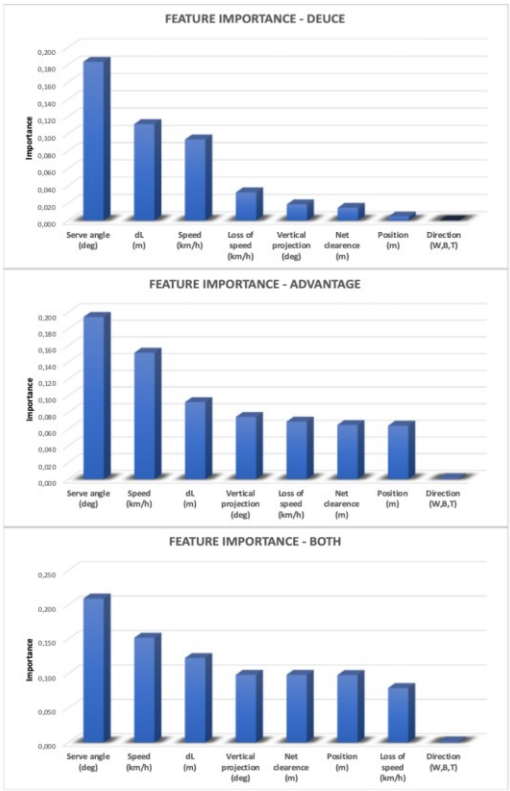

Figure 2. Importance of the variables for the aces in the Deuce, Advantage and Both sides

Results of the predictions using the trained model

Table 2 shows the results of the predictions using the trained model and the synthetic dataset, which resulted from replacing values outside the recommended range with random values within the recommended range. Serve angle values between 5º and 8.7º double the initial probability of making an ace on both the deuce and the advantage side. Similarly, although to a lesser extent, both the variable of serve speed (between 157 – 200 km/h) and the variable of distance to the line < 0.42m, also improve the probability of making an ace, regardless of the side of the court.

Table 2.
Results of the predictions using the trained model

Variable	Side	Values (min-max)	Effectiveness Before (%)	Effectiveness After (%)
Serve angle (deg)	DEUCE	5.5 – 8.7	22.2	48.5
	AD		17.3	45.7
	BOTH		18.7	47.1
Speed (km/h)	DEUCE	157 – 200	18.8	24.3
	AD		16.7	23.9
	BOTH		16.8	22.8
dL (m)	DEUCE	0 – 0.50	20.3	21.7
	AD		16.4	20.3
	BOTH		17.5	20.7

Discussion

This study addressed serve effectiveness in women's doubles tennis, using advanced machine learning techniques to analyze a large dataset collected from BJKC matches. From the analysis of 4939 serves in 65 matches, it was found that serve angle, serve speed and distance to the serve line are critical variables in increasing the likelihood of hitting an ace.

The results shown in Table 2, have determined that serve angles between 5.5º-8.7º have a direct impact on the serving team achievement of an ace in women's professional doubles tennis, increasing the overall probability by 47.1 % (48.5% on the deuce side and 45.7% on the advantage side). These results are in the lines of previous studies in

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both singles and men's doubles tennis, where it was reported that angles from 5.88º and 5.7º, respectively, significantly increased the probability of hitting an ace (Whiteside & Reid, 2017; Vives et al., 2022). These results confirm that, in women's doubles tennis, as in the men's game, employing strategies in which the direction of the serve seeks to place the ball away from the receiver increases the efficiency of the serve partner and, therefore, their chances of winning the point, either through an ace or by taking the initiative of the point (Rioult et al., 2015; Mecheri et al., 2016; Martínez-Gallego et al., 2021a; Vives et al., 2022). However, it is important to note that these improvements in efficiency in women's doubles (≈30 %) are considerably lower than those reported in the men's game (≈50-60 %). This may be due, on the one hand, to the lower overall efficiency of the serve in women's doubles compared to men's doubles (Martínez-Gallego et al., 2021a) and, on the other hand, to the position adopted by the players in the return of serve. In this regard, although there are no data in doubles tennis, in the singles game it has been reported that female players adopt positions closer to the net than male players (Reid et al., 2016). This could allow them to shorten the trajectory of the ball and, therefore, move a shorter distance, thus increasing the likelihood of returning the serve.

The variable of serve speed has been explored due to its impact on the game in several studies, which have found a significant relationship with the probability of winning the point (Rioult et al., 2015). In contrast, no direct relationship has been found between aces and speed in both male and female players (Brown, 2021). However, the results obtained in this study show that, in women's doubles tennis, first serve speed, although limited, does improve the likelihood of hitting an ace. Specifically, it has been found that serves with speeds of 157 km/h and above improve the probability of hitting an ace on both sides of the court by around 5%. These results are in line with those found in men's doubles, where once 187 km/h was exceeded, the probability of an ace was increased by approximately 10% (Vives et al., 2023). Thus, although serve speed is an important variable that has received much attention and interest (Rioult et al., 2015; Grambow et al., 2021; Mecheri et al., 2016), its contribution to improving effectiveness is limited compared to other variables such as angle. Currently, probably due to improved return performance, returners are able to return a very high percentage of serves, even at high speeds (Born et al., 2021; Fitzpatrick et al. 2023), which means that, in isolation, speed is not a determining variable in serve effectiveness. Therefore, it seems reasonable that, although serve speed is an aspect to work on with the players, it would be advisable to integrate it with variables related to direction and angle to maximize effectiveness.

Similar to speed, the distance from the ball bounce to the serve box sideline, although it improves the effectiveness of serves, does so to a limited extent, increasing the probability of hitting an ace by approximately 5% when the distance is less than 0.50 m. These results differ from those observed in men's doubles tennis, where bouncing the ball within 0.28 m of the line was reported to increase the probability of hitting an ace by 50% (Vives et al., 2023). This also contrasts with a study of men's singles tennis, which found that bouncing within 0.15 m of the line significantly increased the probability of hitting an ace (Whiteside and Reid, 2017). These differences are likely due to the interaction of this variable with speed. The fact that male players serve at a higher speed than female players (Brown, 2021) means that, when the ball bounces close to the lines, effectiveness increases to a greater extent. On the other hand, in the case of the female players, although the ball bounces close to the lines, serving at a slower speed allows the receiver to reach the ball in better conditions and, therefore, the serve is less effective.

Even though this study is comprehensive, there are certain limitations that should be taken into account. These limitations also provide some ideas for future research directions in this particular area of study.

One of the key limitations of this study is the isolated analysis of the serve, conducted without considering its impact on subsequent shots or shot patterns that develop later in the game. This approach omits how the characteristics of the serve can affect the dynamics of the point. Future research could analyze the effectiveness of the serve using a more comprehensive approach, by examining how the variables of the serve contribute to the overall development of the game, thus allowing for a more holistic understanding of the various nuances in the strategy of women's doubles tennis.

Another important limitation is the independent analysis of the variables conducted, without exploring the interaction between them. This simplified approach may not fully capture the complexity and multifactorial nature of tennis performance. In this scenario, future research should consider the interactions between variables, which would offer deeper insights into how specific combinations of factors influence serve success in women's doubles.

Finally, the exclusive use of data accessed from the BJKC may limit the absolute applicability of the results to other competitive contexts in women's doubles tennis. The specificity of the sample suggests the need for caution in absolute applying the results. Future research could also extend the analysis to different competitions and levels of play, thus enriching the understanding of serving in women's doubles tennis and its impact on competitive performance. These studies could reveal tactical and strategic variations adapted to different playing contexts, offering a broader and globally applicable perspective.

From a practical application perspective, the results of this study reveal critical aspects that can be considered by coaches and trainers to improve serve effectiveness in women's doubles on court training sessions. The identification of speed, bounce distance to the line, and particularly, serve angle as key variables that increase the likelihood of hitting aces suggests that serve training should prioritize

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these elements. This aligns with the findings of Filipcic et al. (2021), who highlighted the importance of shot angles in their analysis of matchplay characteristics and performance indicators. Therefore, specific technical training that incorporates exercises aimed at improving mechanical variables, such as serve angle and speed, could be particularly beneficial. Furthermore, when planning doubles game strategies, and considering the observed strengths and weaknesses in the opponents, it would be relevant to understand how the variables identified in this study can help not only to improve serving performance, but also in shaping the post-serve game patterns, allowing players to take the initiative from the start of the point.

Conclusions

This study explored the effectiveness of the serve in women's doubles tennis, using advanced machine learning techniques to analyse data collected from Billie Jean King Cup matches. The results revealed that serve angle is the variable that determines the most the likelihood of hitting an ace. Speed and distance to the serve sidelines, although to a lesser extent, were also related to a greater likelihood of hitting an ace. These findings underline the importance of integrating technical, tactical, and biomechanical aspects to improve women's doubles serving performance through the appropriate use of variables. Therefore, it is suggested that coaches and physical trainers focus their serve training sessions on improving the angle and speed of the shot, as well as on improving the strategic selection of serve direction, to enhance the chances of success in women's doubles tennis.

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