Int. j. racket sports sci. vol. 5(2), 2023, 23-31. eISSN: 2695-4508
Original Investigation
DOI: 10.30827/ijrss.33238

The confounding effects of serve speed and ball placement on success of male and female tennis players at The Championships, Wimbledon

Los efectos de confusión de la velocidad del saque y la ubicación de la pelota en el éxito de tenistas hombres y mujeres en el Campeonato de Wimbledon

Rosabel Wong[1] * and Homare Shimada[1]

1 Wimbledon High School, London, England.

Received: 28-06-2023

Accepted: 10-06-2024

Abstract

The impact of serve direction and serve speed on the success of the server winning the point in singles tennis was analysed using data from the Championships, Wimbledon from 2004 to 2019. The direction and speed of the serve are two crucial factors when determining the outcome of a serve and subsequently the point. Gaining maximum advantage from the serve is a priority for tennis players, particularly when competing at The Championships due to the nature of the grass court surface. The data used in this study was collected for Wimbledon Information System (IBM) from The Championship's male and female singles competitions from 2004 to 2019, with permission given by the All-England Lawn Tennis Club. Multi-way ANOVAs were performed for sex of player, server handedness, receiver handedness, serve number, serve side, serve placement, serve speed, and serve success with post-Hoc Tukey and Scheffe tests independently completed for males and females. Data was weighted by frequency and Pearson's chi-square tests (contingency coefficient, Phi and Cramer's V, and Lambda) were conducted independently for males and females for the aforementioned categories. Additionally, z-tests were used to compare proportions, and standardized residuals with adjusted p-values were used to analyse significant effects. The analysis revealed that in male singles, servers are more likely to win the point regardless of other serve characteristics, with serve placement into the centre and wide areas further increasing the probability of winning the point. In female singles, the likelihood of the server winning the point varied more with certain serve combinations, largely influenced by serve placement and serve number. The relationship between serve placement and serve speed indicated that certain speeds were favoured for both male and female matches in all serve directions, with two distinct peaks and serves around 190 km/h being disfavoured.

Keywords: *Grand Slam, Wimbledon, speed, placement, handedness.*

Resumen

Se analizó el impacto de la dirección y la velocidad del saque en el éxito del servidor que gana el punto en el tenis individual usando datos de los Campeonatos de Wimbledon de 2004 a 2019. La dirección y velocidad del saque son dos factores cruciales para determinar el resultado de un saque y, posteriormente, del punto. Obtener la mayor ventaja en el saque es prioritario para los tenistas, particularmente, cuando compiten en el Campeonato de Wimbledon, debido a la naturaleza de la superficie del campo de césped. Los datos usados en este estudio fueron recolectados por el Sistema de Información de Wimbledon de IBM en las categorías individuales masculinas y femeninas de los campeonatos de 2004 a 2019 con el permiso de All England Lawn Tennis Club. Se aplicaron modelos ANOVA multifactoriales para el sexo del jugador, la mano dominante del servidor, la mano dominante del receptor, el número de saques, el lado del saque,

Corresponding author: Rosabel Wong, rosabelvwong@icloud.com

Cite this article as:
Wong, R., & Shimada, H. (2023). The confounding effects of serve speed and ball placement on success of male and female tennis players at The Championships, Wimbledon. *International Journal of Racket Sports Science, 5*(2), 23-31.

la ubicación del saque, la velocidad del saque y el éxito del saque con pruebas post hoc de Tukey y Scheffe realizadas de manera independiente para hombres y mujeres. Los datos se ponderaron por frecuencia y las pruebas de ji al cuadrado de Pearson (coeficiente de contingencia, Phi y V de Cramer, y Lambda) se realizaron de forma independiente para hombres y mujeres en las categorías ya mencionadas. Adicionalmente, se realizaron pruebas Z para comparar las proporciones, y se usaron residuales estandarizados con valores p ajustados para analizar los efectos significativos. El análisis evidenció que en los individuales masculinos es más probable que los servidores ganen el punto sin importar las otras características del saque, y cuando el saque llega al centro y a las zonas amplias aumenta aún más la probabilidad de ganar el punto. En los individuales femeninos, la probabilidad de que la servidora gane el punto varió más con ciertas combinaciones de saque, influenciado en gran parte por la ubicación del saque y el número de saque. La relación entre ubicación y velocidad del saque indicó que ciertas velocidades eran preferidas por tanto hombres como mujeres en todas las direcciones del saque, y que dos picos distintivos y los servicios de cerca de 190 km/h son menos preferidos.

Palabras clave: *Grand Slam, Wimbledon, velocidad, ubicación, mano dominante.*

INTRODUCTION

The tennis serve is an important factor in controlling the outcome of the game, being the only closed skill in the sport. Gaining maximum advantage from the serve is a priority for tennis players (O'Donoghue & Ingram, 2001) and it is well reported that players win more points when serving (Brown & O'Donoghue, 2008; Fitzpatrick et al., 2019). For both male and female players, points from a one-shot rally comprise almost half of all short points for male players and over a third of all points for female players. This highlights the importance of the serve in the outcome of the point and subsequently the match. Players who can serve and win the point through aces or unreturned serves have a greater than 70% probability of winning the match (Fitzpatrick et al., 2021).

This study focussed exclusively on grass courts at The Championships, Wimbledon. Brown and O'Donoghue (2008) reported that average rally lengths at Wimbledon are shorter than those at other Grand Slam tournaments. Therefore, the server has an even greater advantage at Wimbledon than at other tournaments (Paserman, 2020). Compared with clay, grass reduces the angle at which the ball bounces and grass has less of a slowing effect on the ball due to a decreased friction coefficient (Vaverka et al., 2018).

There have been numerous studies that have shown that faster serve speeds are associated with increased success in winning points (McMahon et al., 2002; O'Donoghue & Ballantyne; 2004; Whiteside et al., 2015; Brown, 2021). However increased serve speed is also associated with reduced accuracy of ball placement. O'Donoghue & Ballantyne (2004) proposed this as the rationale behind the common strategy where players hit powerful first serves, making the return shot harder for the receiver, but reduce the speed of the second serve putting more focus on serve placement accuracy.

The purpose of this study is to examine the relationship between serve speed and ball placement and the impact of variables such as sex of player, server handedness, serve number and serve side on the probability of the server winning the point. Previous studies have explored handedness, serve speed and ball placement, however, this study focuses on analysing the confounding effects of all these factors on the server winning the point in both the men's and ladies' singles events at The Championships, Wimbledon, providing new insights into the serve strategies for grass court specialists.

METHOD

Sample

This study used official championship performance information from the Wimbledon Information System (presented by IBM) from The Championship's men's and ladies' singles competitions from 2004 to 2019. This data is not in the public domain so permission to access this data was given by IBM with permission granted by the All-England Lawn Tennis Club.

For the purpose of this study, serve success is defined as the number of points won by the server as a percentage of all points played that were won within five shots. Serve placement was determined by data collectors positioned on the side of each show court and was based on the angle of the ball's trajectory from the server's racket to the location within the service box where the serve lands. Serve placement within the service box was categorised into one of three areas, the innermost division (centre), outermost division (wide), and the body segment, flanked by the centre and wide segments as illustrated in Figure 1. This subjective measurement was made relatively objective by validation using data collected by Hawkeye cameras (hawkeyeinnovations.com, n.d.) for automated ball-tracking data collection, rendering a minimum of 97% accuracy and consistency rate by the data collectors.

Serve speed was recorded as an integer value in miles per hour using a radar gun that measured the maximum speed of each serve as soon as the ball

left the server's racket. Robinson & Robinson (2016) demonstrated the reliability of these radar guns to record the ball throughout its flight path to accurately determine the ball's speed from when the served ball leaves the server's racket.

Data was separated based on whether the first or second serve was played out for the point as players tend to adopt a more conservative approach for their second serve. For second serves, serve speed decreases by 24.1% on average and the ball's trajectory moves further from the edges of the service box into the middle (Chow et al, 2003).

Procedure

The data was filtered to include: sex of player, serve number (first or second serve), serve side (advantage or deuce), serve placement (body, centre or wide), handedness (right-handed server to right-handed receiver (RvR), right-handed server to left-handed receiver (RvL), left-handed server to right-handed receiver (LvR) or left-handed server to left-handed receiver (LvL)), serve speed, and serve success. The data was further filtered to remove points that continued longer than 5 shots as serve characteristics are most influential for rallies of length up to four shots and 66% of points at Wimbledon end within the first four shots (Carboch et al., 2019). Double faults were also not included as these are unsuccessful serves that do not satisfy the serve placement criteria (Fitzpatrick et al., 2021). The total number of points included in each serve combination ranged between 42 and 29 896 points for males and 5 and 24 192 points for females (Table 1).

Statistical Analysis

All statistical analyses were performed with SPSS ver. 28 (and values are expressed as mean ± standard deviation) to determine the strength of association between serve speed and serve placement and each of the examined variables. Successful serve frequencies for each combination were checked for normality using the Kolmogorov Smirnov test to ensure distribution of data for the comparison of the impacting variables. Significance of differences between serve combinations were compared using significant standardised residuals from Pearson's chi-square cross tabulations and likelihood ratios. Due to there being too few points played between two left-handed players in female matches for meaningful analysis, these data were excluded from these analyses.

Table 1
Total number of points analysed in this study for each combination of handedness for singles matches at The Championships, Wimbledon 2004-2019

Group	n
Female RvR	151590
Female RvL	9000
Female LvL	393
Female LvR	9132
Male RvR	223986
Male RvL	31668
Male LvL	6646
Male LvR	31708

Legend: RvR: Right-handed player vs Right-handed player. **RvL:** Right-handed player vs Left-handed player. **LvL:** Left-handed player vs Left-handed player. **LvR:** Left-handed player vs Right-handed player. **n:** number of points in each category.

Multi-way ANOVAs, completed with post-Hoc Tukey and Scheffe tests were performed for males and females separately (sex of player, server handedness, receiver handedness, serve number, serve side, serve placement, serve speed, and serve success) to find the effects of the given variables on the probability of the server winning the point. Statistical difference was set at $p < 0.05$.

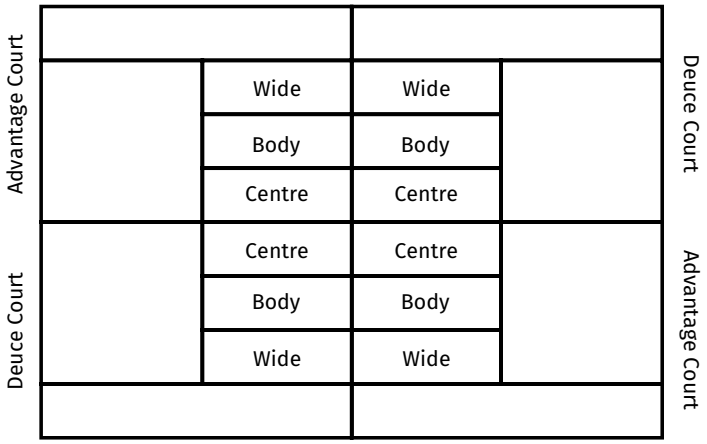

Figure 1. A representation of the deuce and advantage boxes divided into their respective Body, Centre and Wide regions.

Data was weighted by frequency and Pearson's chi-square tests (contingency coefficient, Phi and Cramer's V, and Lambda) were conducted independently for males and females for the categories of sex of player, serve handedness, receiver handedness, serve number, serve side, serve placement, and serve success. The contingency coefficient and Cramer's V test measured the interdependence between each pair of categorical variables which can be used to compare the strength of relationship between each category and serve speed and placement. The Phi test was performed to indicate the direction of the degree of relevance measured by the contingency coefficient between each pair of variables. The Lambda test assessed the strength and direction of association between a dichotomous variable and categorical variable based on how the dichotomous variable influences the distribution of categories in the categorical variable. *z* tests to compare proportions, and standardised residuals with adjusted p values were used to analyse significant effects. Statistical difference was set at $p < 0.05$.

RESULTS

Four-way interaction (handedness, court side (advantage/deuce), service number and serve placement interaction) was significant for both males and females, male likelihood ratio $x^2(1) = 2165.05$, $p < 0.000$ and female likelihood ratio $x^2(1) = 424.82$, $p < 0.001$. The combined effects of these four factors in this interaction has some of the most significant effects on serve success, (z=17.530 for males) and (z=6.421 for females). The effect of this interaction is significantly higher for males than for females but is nonetheless significant for both.

The cross-tabulation test shows that significantly fewer points than expected are won by the server for Centre, first serves from the advantage court for LvR, as depicted by the negative significant standardised residual values of -6.9 and -2.1 for men and ladies respectively in Tables 2 and 3.

Table 2
Percentage of points where the server wins the point for each combination of serve placement, courtside, service number and handedness for males at The Championships, Wimbledon 2004-2019

Body																
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	73.9	65.4	69.1	67.2	58.6	56.6	59.4	56.2	69.5	67.8	67.3	68.4	58.3	56.4	57.5	57.2
Sig Standardised Residual	-1.7	1.1	-1.4	-0.4	0.4	0.5	-1.5	0.4	-0.4	0.0	0.3	-0.3	0.4	0.4	-0.6	-0.4
Centre																
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	76.5	72.5	78.7	71.4	55.2	59.7	62.6	57.1	69.9	77.5	70.9	78.2	54.2	57.1	57.4	61.7
Sig Standardised Residual	1.0	-1.1	-6.9	2.2	1.0	-0.5	-1.5	1.7	4.3	-3.5	9.1	-2.4	0.9	0.5	0.0	-2.3
Wide																
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	73.7	75.2	73.2	78.5	56.3	56.3	59.7	61.9	73.1	73.7	74.8	74.3	54.5	61.3	61.5	57.5
Sig Standardised Residual	1.0	0.1	3.1	-4.3	0.2	1.5	-2.0	-3.1	0.4	0.5	-1.2	-0.6	1.8	-1.4	-0.6	2.5

R: Right-handed. L: Left-handed

Table 3
Percentage of points where the server wins the point for each combination of serve placement, courtside, service number and handedness for females at The Championships, Wimbledon 2004-2019

Body																
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	55.6	59.0	61.3	59.8	36.8	51.8	52.5	52.8	51.7	59.4	59.9	60.3	51.6	53.2	49.6	57.6
Sig Standardised Residual	0.3	0.2	-0.7	0.2	0.9	0.2	-0.4	0.5	0.7	0.1	-0.2	0.3	0.1	0.1	1.3	-1.6

Table 3
Percentage of points where the server wins the point for each combination of serve placement, courtside, service number and handedness for females at The Championships, Wimbledon 2004-2019 (Continued)

								Centre									
Court Side				Advantage								Deuce					
Service Number	1st				2nd				1st				2nd				
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	
% Server Wins Point	74.6	64.4	67.9	64.8	50.0	53.1	57.2	53.7	62.3	67.9	61.8	69.8	52.0	52.5	53.9	54.7	
Sig Standardised Residual	-1.3	0.5	-2.1	-0.2	0.2	0.2	0.9	0.2	0.8	-1.0	4.9	-1.6	0.1	0.3	-0.6	-0.6	
								Wide									
Court Side				Advantage								Deuce					
Service Number	1st				2nd				1st				2nd				
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	
% Server Wins Point	72.4	66.6	65.2	64.9	57.6	53.0	54.0	53.9	69.7	65.9	65.9	65.5	47.8	55.1	61.1	55.0	
Sig Standardised Residual	-0.9	-0.5	1.1	1.1	-0.4	0.2	0.4	0.3	-0.6	-0.1	0.0	-0.3	0.5	0.3	-1.8	0.1	

R: Right-handed. L: Left-handed

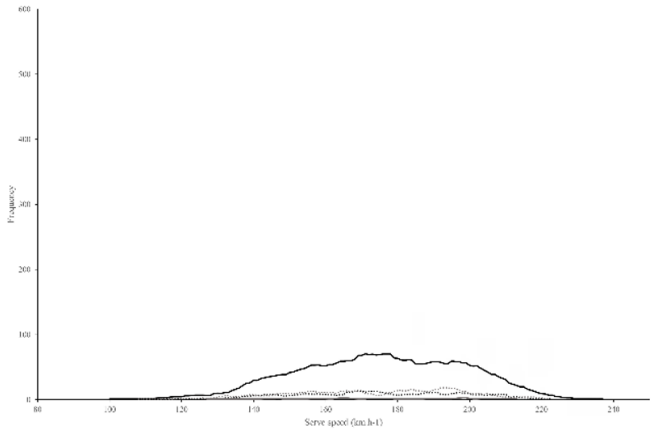

Figure 2. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

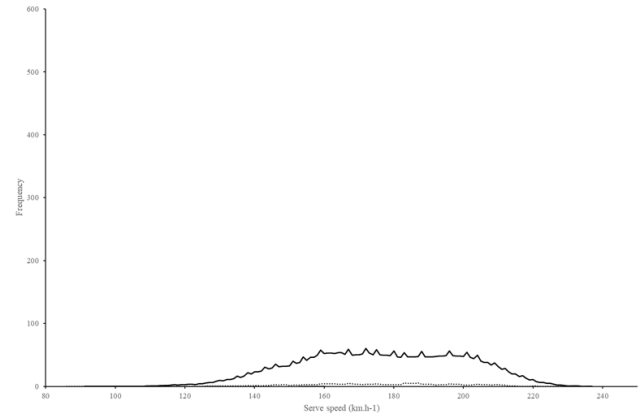

Figure 3. *Relationship between serve speed (km/h) and serve frequency for female first serve right handed player to right handed player (solid, black line), female first serve right handed player to left handed player (dotted, black line), female first serve left handed player to left handed player (solid, grey line) and female first serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

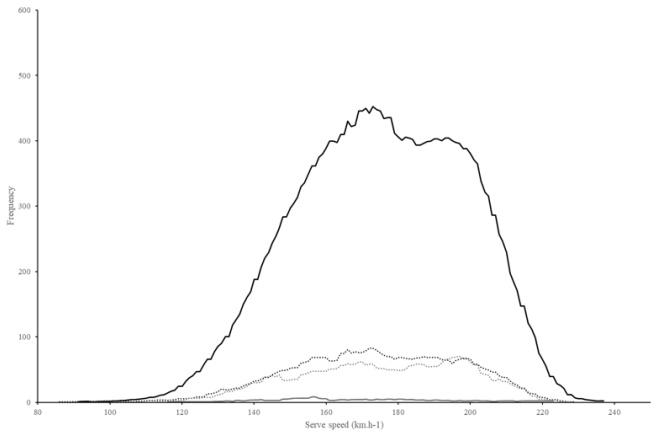

Figure 4. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

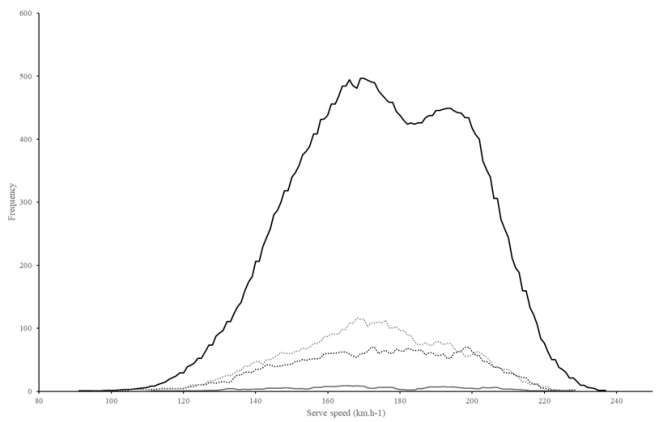

Figure 5. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the wide from the ad side at The Championships, Wimbledon 2004–2019.*

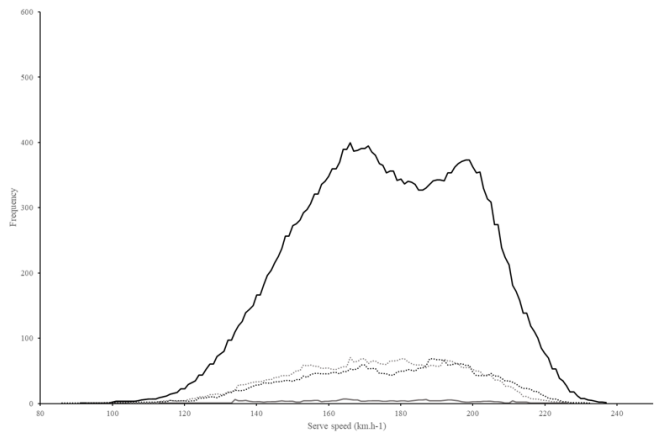

Figure 6. *Relationship between serve speed (km/h) and successful serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the centre from the deuce side at The Championships, Wimbledon 2004–2019.*

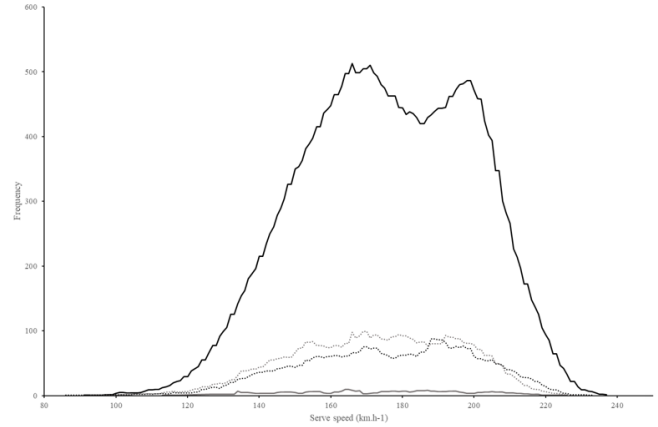

Figure 7. *Relationship between serve speed (km/h) and serve frequency for female first serve right-handed player to right handed player (solid, black line), female first serve right handed player to left handed player (dotted, black line), female first serve left handed player to left handed player (solid, grey line) and female first serve left handed player to right handed player (dotted, grey line) when the serve landed down the centre from the deuce side at The Championships, Wimbledon 2004–2019.*

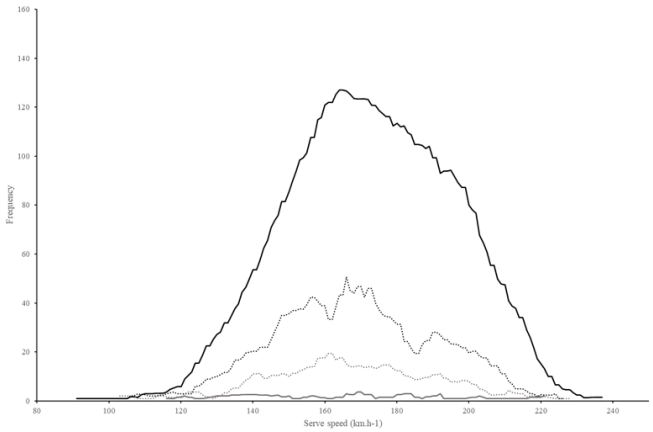

Figure 8. *Relationship between serve speed (km/h) and serve frequency for male second serve right handed player to right handed player (solid, black line), male second serve right handed player to left handed player (dotted, black line), male second serve left handed player to left handed player (solid, grey line) and male second serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

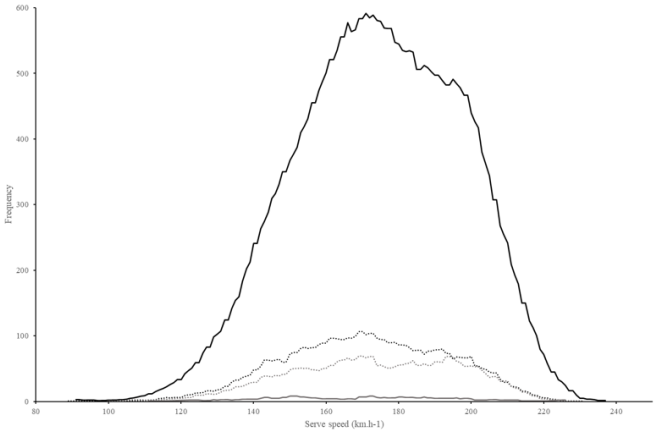

Figure 9. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the wide from the deuce side at The Championships, Wimbledon 2004–2019.*

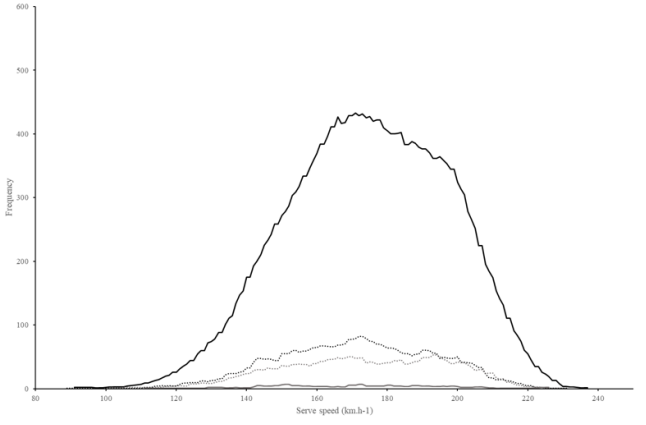

Figure 10. *Relationship between serve speed (km/h) and successful serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the wide from the deuce side at The Championships, Wimbledon 2004–2019.*

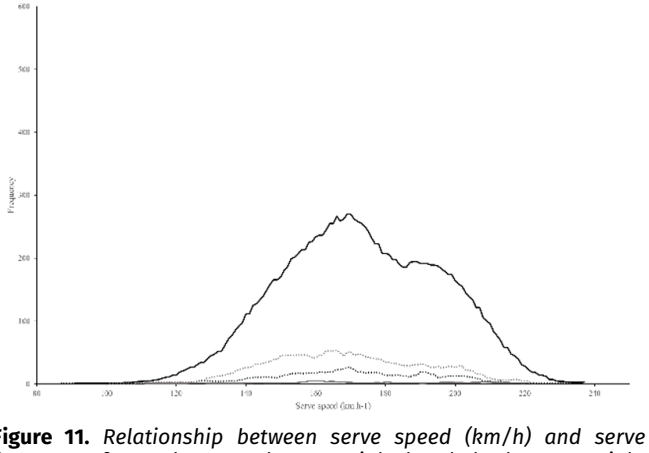

Figure 11. *Relationship between serve speed (km/h) and serve frequency for male second serve right-handed player to right handed player (solid, black line), male second serve right handed player to left handed player (dotted, black line), male second serve left handed player to left handed player (solid, grey line) and male second serve left handed player to right handed player (dotted, grey line) when the serve landed down the centre from the deuce side at The Championships, Wimbledon 2004–2019.*

DISCUSSION

Table 1 shows that for males, servers are more likely to win the point regardless of their handedness, the handedness of their opponent, serve placement, courtside or serve number. Serve placement into the centre and wide areas was found to increase the likelihood of players winning the point (Mecheri et al., 2016). This echoes previous findings that male players adopt more strategic serving patterns as this significantly contributes towards increasing the probability of them winning the point outright through an ace or forced error, or through increasing their control over the next few shots in the rally so that the server is more likely to win the point (Hizan et al., 2015). For RvR points, servers have the highest likelihood of winning the point for first serves from the deuce court side directed towards the centre of the court. This may be due to the receiver covering the tramlines, so they are less prepared for a serve down the centre line and have less reach to make their return. This serve is directed towards the receiver's backhand which is usually weaker and may lead to a single-handed slice backhand which is less likely to be a winner. For RvL points, servers are most likely to win the point for first serves directed out wide from the advantage court side as these serves may have topspin that causes the ball to move towards the tramlines and draws the receiver away from the centre of the court, so they have further to recover before the next shot. For LvL points, servers have the highest probability of winning the point for first serves directed to the centre of the court from the advantage court side as these serves are directed towards the receiver's backhand which tends to be weaker, and the receiver may have less reach particularly if they have a double-handed backhand which further weakens the return of serve. This result aligns with Gillet et al. (2009), who showed that flat serves are the favoured serve type on the grass surface due to their higher winning point rate compared to topspin and slice serves, particularly when serving down the centre of the court. This is largely due to flat serves achieving faster speeds and lower bounce which reduces the time receivers have to execute a strong return, particularly if the receiver has to move from near the tramlines towards the "T", increasing the probability of the server winning the point. For LvR points, servers have the highest likelihood of winning the point for 1st serves directed towards the centre of the court from the advantage court side as these serves are aimed towards the centre line which may be difficult to return if the receiver is covering the tramlines. Loffing et al. (2009) suggested that because there are far fewer left-handed players, the lack of experience of right-handed players in receiving shots with different spins from left-handed players creates a significant advantage for the latter.

Table 2 shows that for females, servers are less likely to win the point on the following serve combinations; LvL second serves directed towards the body from the advantage court side; LvR second serves directed towards the body from the advantage court side; and LvL second serves directed towards the body of a left-handed receiver from the deuce court side. Receivers were more likely to win the point for these serve combinations as second serves tend to be slower than first serves (Mecheri et al., 2016) and these serves are directed towards the receiver making it easier for them to make a winning return of serve. The second serve is a different proposition where the server adopts a safer approach as a fault leads to the loss of the point so a larger proportion of second serves are directed towards the body of the receiver (Hizan et al., 2015). This study shows that the LvL and RvL wide serves from the deuce side have a higher probability of the server losing the point as the serve is directed towards the backhand of the receiver which is likely to be a double-handed backhand that is a strength of female players (Hizan et al., 2015). For all other serve combinations, the server has a higher likelihood of winning the point. This includes for body serves which are a relatively safer approach for servers (Hizan et al., 2015) but may lead to the receiver hitting a forced error in their return if the body serve is executed well (Crespo and Miley, 1998).

Mecheri et al. (2016) showed that the most first serves were directed toward the centre and wide serve placement locations in a similar manner on both deuce and advantage courts for both males and females. The first serve is usually faster than the second serve and more likely to land in the centre and wide serve placement locations as these serves are directed further away from the receiver so returns of serve are weaker and more difficult (Crespo and Miley, 1998, Hizan et al., 2015, Unierzyski et al., 2004, Gillet et al., 2009). This study shows that for second serves those on the deuce court are more likely to be directed towards the centre of the court and on the advantage court second serves are more likely to be directed towards the tramlines. This choice of second serve placement enables the server to aim for their opponent's backhand which will more likely result in a weaker return of serve. Second serves on the deuce court side are more likely to be directed towards the centre of the court with more topspin to push the receiver behind the baseline whereas second serves on the advantage court side are more likely to be wide and with less topspin to open up the court.

Figures 2 and 3 suggest that serve speeds to the body are not significantly different to the speeds of the other serve directions for males while the distribution of serve speeds are different for females. This is reflected in the post hoc Tukey and Scheffe test, which show that the serve speeds to the body are not significantly different compared to the centre and wide serves. For females, handedness has a significant factor in the frequency of successful serves.

Figures 4, 5, 6 and 7 reflect a trend of having two clear peaks, where speeds near 190 km/h are less favoured. Further analysis uncovered that this is because of two peaks that are superimposed on each other. When dividing the data into the earlier time period (2004 -

2011) and the later time period (2012 - 2019), the two peaks were visible, with the earlier time period peaking at the lower speed and the later time period peaking at the higher speed. This trend can also be seen on Figures 8, 9 and 10 where the serve frequency seems to gather near one serve speed. There is approximately a 40 km/h difference between where the serve frequency is highest in the earlier time period (160 km/h) compared with the later time period (200 km/h). This may be for several reasons such as racket material and a change in the strength and conditioning of players. Mainstream racket material has not changed significantly in the past 20 years, major changes in materials of rackets was the change from graphite combined with Kevlar to carbon fibre combined with certain types of resins at around 2010 (Koronas and Tohanean, 2021). However, the improvement on rackets have been largely focused on increasing reliability rather than power being shot (Koronas and Tohanean, 2021). Another factor that may affect the speed of serves in a short time period is the types of strings used on the racket. While strings have not changed much, changing technologies have improved player performance (Ozdemir et al., 2019).

Finally, another factor that may affect the speed is strength and conditioning. The increased popularity of strength and conditioning has allowed players to focus on increasing power behind each of their shots. For example, current younger players who are training with the Youth Physical Development model will have trained to improve all physical qualities, including muscular strength from an early age (Fernandez-Fernandez and Kovacs, 2018). Increased muscular strength will lead to shots with more power and more speed. Strength training from a young age under the correct supervision is proved to be beneficial (Fernandez-Fernandez and Kovacs, 2018). As youth players receiving strength training reach the age to qualify for The Championships, Wimbledon, the results may be mirrored into the increased speed of serves.

Figures 8 and 11 show that the most popular serve direction on the second serve is down the centre at 163 km/h. This direction is favoured as players often focus on putting the ball into the service box rather than the powerful, higher speed serves seen in the first serve. By serving down the centre, it allows the player to improve the chances of serving into the service box, as well as serving to the area where the distance between the player serving and the serve direction is the shortest, however, it allows the receiving player to hit harder return shots, as it allows them to have the longest reaction time. However, these shots can be easily returned, and so they have the lowest absolute success frequency compared to other serve directions.

Since higher seeded players are more likely to progress to further rounds and qualify to compete for many years during their career, these players will be overrepresented in this study. Further studies to reduce this effect would be valuable. Other limitations include the subjectivity of the measure of serve placement and the fact that radar gun only measures the exact bounce spot of the serve and does not provide any data for the direction of the serve after it bounces. (Whiteside et al., 2015; Mecheri et al. 2016).

Previous studies have shown that players' serve performance, particularly serve speed, both peak and average, decreased gradually between the first and fifth set so the number of serve winners declined (Cui et al., 2020). Further research could be conducted to analyse the impact of match fatigue on the success of each serve combination.

This study depicts the significant impact of these confounding variables on serve speed and ball placement and therefore due to the influence of the serve for the rest of the point, the probability of the server winning the point. These results are useful for informing players and their coaches about the most successful serve strategies for winning points when competing at The Championships, Wimbledon and other tournaments.

ACKNOWLEDGEMENTS

The authors would like to express their sincere gratitude for the All-England Lawn Tennis Club and IBM for providing this data and Dr Clare Roper, Catriona Coutts-Wood, Keith Sohl and Dr Shilo Dormehl for their assistance. The authors declare there is no conflict of interests.

REFERENCES

Brown, E. G. (2021). A faster serve has more impact on success for female elite tennis players than males. *International Journal of Performance Analysis in Sport*, *21*(4), 600-610 https://doi.org/10.1080/24748668.2021.1931777

Brown, E., & O'Donoghue, P. (2008). Gender and surface effect on elite tennis strategy. *ITF Coaching and Sport Science Review, 46*(12), 9-12. https://doi.org/10.1080/24748668.2008.11868449

Carboch, J., Siman, J., Sklenarik, M., & Blau, M. (2019). Match Characteristics and Rally Pace of Male Tennis Matches in Three Grand Slam Tournaments. Physical Activity Review, (7), 49-56. https://doi.org/10.16926/par.2019.07.06

Chow, J. W., Carlton, L. G., Lim, Y. T., Chae, W. S., Shim, J. H., Kuenster, A. F., & Kokubun, K. (2003). Comparing the pre- and post-impact ball and racquet kinematics of elite tennis players' first and second serves: a preliminary study. *Journal of sports sciences, 21*(7), 529-537. https://doi.org/10.1080/0264041031000101908

Crespo, M., & Miley, D. (1998). *Advanced Coaches Manual.* International Tennis Federation.

Cui, Y., Liu, H., Gómez, MÁ., Liu, H., & Gonçalves, B. (2020). Set-to-set Performance Variation in Tennis Grand Slams: Play with Consistency and Risks. Journal of Human Kinetics, *73*(1), 153-163. https://doi.org/10.2478/hukin-2019-0140

Deniz Dindar, M., Toksöz, I., Taskin, C., & Uluçam, E. (2011). Analysis of the Serves in the Men's Semi-Final and Final Competitions of Wimbledon Tennis Tournament. *e-Journal of New World Sciences Academy Sports Sciences, 6*(3), 185-192. https://dergipark.org.tr/en/pub/nwsaspor/issue/20136/213788

Fernandez-Fernandez, J., Kovacs, M. (2018). Strength and Conditioning in Developmental Tennis Players: A Complete Guide to Evaluation, Treatment, and Rehabilitation. In G. Di Giacomo, T. Ellenbecker, & W. Kibler (Eds), *Tennis Medicine* (pp. 611-626). Springer, Cham. https://doi.org/10.1007/978-3-319-71498-1_38

Filipcic, A. (2001). Birth date and success in tennis. *ITF–Coaching & Sport Science Review,* (23), 9-11. https://www.itf-academy.com/content/itf_download_file.php?file_itf=https://d33so9os8hjs13.cloudfront.net/itfcontents/CSSR%2023%20ENG.pdf

Fitzpatrick, A., Stone, J., Choppin, S., & Kelley, J. (2019). Important performance characteristics in elite clay and grass court tennis match-play. *International Journal of Performance Analysis in Sport, 19*(6), 942-952. https://doi.org/10.1080/24748668.2019.1685804

Fitzpatrick, A., Stone, J. A., Choppin, S., & Kelley, J. (2021). Investigating the most important aspect of elite grass court tennis: Short points. *International Journal of Sports Science & Coaching, 16*(5), 1178-1186. https://journals.sagepub.com/doi/10.1177/1747954121999593

Gillet, E., Leroy, D., Thouvarecq, R., & Stein, J. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. *Journal of Strength & Conditioning Research, 23*(2), 532-539. https://doi.org/10.1519/JSC.0b013e31818efe29

hawkeyeinnovations.com (online) (n.d.). *Hawk-Eye innovations.* https://resources.platform.pulselive.com/HawkEye/document/2016/07/29/ec84be34-2375-4b5a-8854-917e0e7021f0/Hawk EyeinTennis2016.pdf

Hizan, H., Whipp, P., & Reid, M. (2015). Gender Differences in the Spatial Distributions of the Tennis Serve. *International Journal of Sports Science & Coaching, 10(1), 87-96. https://doi.org/10.1260/1747-9541.10.1*

Loffing, F., Hagemann, N., & Strauss, B. (2009). The serve in professional men's tennis: Effects of players' handedness. *International Journal of Performance Analysis in Sport, 9*(2), 255-274. https://doi.org/10.1080/24748668.2009.11868482

Koronas, V., & Tohănean, D. (2021). Evolution of material for tennis racket frame manufacture. *Theory and Practice of Physical Culture*, (5), 66-69. https://cyberleninka.ru/article/n/evolution-of-material-for-tennis-racket-frame-manufacture

McMahon, G., De Mestre, N., & Coast, G. (2002). Tennis serving strategies. *Proceedings of the Sixth Australian Conference on Mathematics and Computers in Sport*, 177-181. http://www.mathsportinternational.com/anziam/Mathsport%206.pdf#page=186

Mecheri, S., Rioult, F., Mantel, B., Kauffmann, F., & Benguigui, N. (2016). The Serve Impact in Tennis: First Large-Scale Study of Big Hawk-Eye Data. Statistical Analysis and Data Mining: The ASA Data Science Journal. 9(5), 310-325. https://doi.org/10.1002/sam.11316

O'Donoghue, P., & Ballantyne, A. (2004). The impact of speed of service in Grand Slam singles tennis. In *Science and Racket Sports III: The Proceedings of the Eighth International Table Tennis Federation Sports Science Congress and the Third World Congress of Science and Racket Sports.*

O'Donoghue, P., & Ingram, B. (2001). A notational analysis of elite tennis strategy. *Journal of Sports Science, 19*(2), 107-115. https://doi.org/10.1080/026404101300036299

Ozdemir, O., Odabas, I., & Turan, T. (2019). Impact of Racquet Evolution: How New Technologies Affected Tennis Players' Statistics? *Pamukkale Journal of Sport Sciences, 10*(2), 10-16. https://dergipark.org.tr/en/pub/psbd/issue/48585/410858

Paserman, M. D. (2020). Gender Differences in Performance in Competitive Environments? Evidence from Professional Tennis Players. *Journal of Economic Behavior & Organization, 212,* 590-609. https://doi.org/10.1016/j.jebo.2023.05.042

Robinson, G., & Robinson, I. (2016). Radar speed gun true velocity measurements of sports-balls in flight: application to tennis. *Physica Scripta, 91*(2). https://doi.org/10.1088/0031-8949/91/2/023008

Unierzyski, P., & Hurnik, E. (2004). *Does practising on clay affect the level of motor abilities of tennis players?* Science and Racket Sports III: The Proceedings of the Eighth International Table Tennis Federation Sports Science Congress and The Third World Congress of Science and Racket Sports.

Vaverka, F., Nykodym, J., Hendl, J., & Zhanel, D. Z. (2018). Association between serve speed and court surface in tennis. *International Journal of Performance Analysis in Sport, 18*(2), 262–272. https://doi.org/10.1080/24748668.2018.1467995

Whiteside, D., Bane, M., & Reid, M. (2015). *Differentiating top-ranked male tennis players from lower-ranked players using Hawk-Eye data: An investigation of the 2012–2014 Australian Open tournaments.* 33rd International Conference on Biomechanics in Sports, Poitiers, France.