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Analysing Hawk-Eye ball-tracking data to explore successful serving and returning strategies at Wimbledon

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ABSTRACT

Investigations of elite tennis match-play have highlighted the importance of serving and returning strategies. This study establishes the most common and effective strategies used by male and female players at Wimbledon, and identifies associated winner-loser differences. Hawk-Eye ball-tracking data from 302 men's and 139 women's singles matches contested between 2016 and 2018 were analysed using confidence intervals, Chi-square and Chi-square partitions. For both sexes, first serves to lateral areas (Zones A and D) of the service boxes were more common and more successful than first serves to central areas (Zones B and C). Second serves to lateral areas also tended to be more successful than those to central areas, but players typically prioritised safety, often executing second serves to Zone C (central, but towards the backhand of right-handed opponents). Men and women hit more serve-returns to central areas than lateral areas of the court, despite serve-returns to lateral areas being more successful. Furthermore, winning male players were more accurate than losing male players, executing a comparatively higher percentage of serves and returns to lateral areas; winning female players demonstrated this on first serves only. These findings can be used to improve the specificity and representativeness of players' grass court training.

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Hawk-Eye; elite tennis; strategy; successful performance; Wimbledon

1. Introduction

Originally, the recording of tennis notational analysis data was limited to basic characteristics such as stroke type, point outcome and rally length due to a lack of automated techniques (Mecheri et al., 2016), and as these measures were sufficiently objective to be recorded live with good reliability. In recent years, technological advancements, including the development of Global Positioning Systems (GPS) and automated tracking software, have increased our capacity to collect a wider range of performance characteristics (Mecheri et al., 2016). For example, Hawk-Eye technology (Hawk-Eye Innovations ltd, Basingstoke, UK) has enabled automated, ball-tracking data collection, on a shot-by-shot basis. Hawk-Eye uses up to 10 high-speed (60 Hz) calibrated cameras to continually track

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the location of a tennis ball during a match. The system was originally introduced to allow players to "challenge" line calls made by match officials (Kolbinger & Lames, 2013), but its implementation has also benefitted those in coaching, research, broadcasting and digital media professions, as well as enhancing fan engagement (Hawk-Eye, 2020). From a research perspective, Hawk-Eye has facilitated the collection of a wealth of performance data and, in turn, provided extensive opportunities for analysis (Reid et al., 2016). Wimbledon installed Hawk-Eye camera systems on Centre Court and Court One in 2007, and by 2015, the technology was in place on six courts (Hawk-Eye, 2015b), allowing data to be collected from a more representative sample of elite tennis matches.

Thus far, studies analysing Hawk-Eye data in tennis have investigated the influence of serve characteristics (serve speed and spin rate of the ball) on point-winning probability (Mecheri et al., 2016), identified the different types of strokes performed by elite players (Kovalchik & Reid, 2018), compared the technical and physical demands of junior and senior match-play (Kovalchik & Reid, 2017), and established change of direction movement demands on hard courts (Giles et al., 2021). Results from these studies have facilitated several practical applications, with perhaps the most relevant for coaches being provided by Reid et al. (2016), who were able to inform sex-specific training designs for elite players preparing for the hard-court season. These authors also highlighted the importance of future research investigating tennis Hawk-Eye data, to assist practitioners who are aiming to provide more evidence-based training programmes (Reid et al., 2016).

Previous research has demonstrated that *points won of 0–4 shot rally length* (i.e. short points) is the most important performance characteristic at Wimbledon for players of both sexes (Fitzpatrick et al., 2019), and that the serve and serve-return are crucial for winning short points (Fitzpatrick et al., 2021). Further emphasising the importance of the serve and serve-return in elite tennis, Antoun (2007) observed that traditional gamestyles (e.g. serve-volleying, baseline play, all-court play) have become less relevant, and highlighted that the aim for most players is to gain control of the point as early as possible. To do this, players often execute pre-planned strategies, whereby each stroke is hit to a specific area of the court. The key to successful strategies is understanding where to direct the ball, such that each stroke builds on the previous stroke (Antoun, 2007). For example, a particular serve may be executed to elicit a specific serve-return from the opponent, which the server can anticipate, allowing them to better prepare for their next stroke (Rive & Williams, 2011).

Existing investigations into the serving and returning strategies executed by elite players are limited. Gillet et al. (2009) analysed elite men's serving and returning strategies on clay courts, but television recordings were used to estimate the ball-landing location of each stroke (and infer serve and serve-return strategies), the reliability of which is questionable (Yan, 2007). Brown (2021) revealed a positive correlation between serve speed and the percentage of points won on first and second serve by players of both sexes at Wimbledon, but also noted that serve placement (while not included in the study) may be more influential than serve speed. Mecheri et al. (2016) investigated serving strategies, reporting that players tended to aim their first serves close to the lateral edges of the service box and their second serves towards the opponent's backhand, however, their analysis was not stratified by court surface, making surface-specific interpretations difficult. Martinez-Gallego et al. (2021) investigated serving

strategies in Billie Jean King Cup and Davis Cup doubles matches. Findings revealed that players tended to serve towards the lateral edges of the service box on first serves, aiming to take control of the point, whereas second serves were more commonly directly to central areas to reduce error risk (Martinez-Gallego et al., 2021); however, the study did not examine singles matches. Other serve and serve-return based studies were undertaken prior to the introduction of Hawk-Eye technology and/or were often restricted in their sample size (Gollub, 2021; e.g. $n = 2$ matches; Unierzyski & Wieczorek, 2004). Since the introduction of Hawk-Eye, research has not sought to identify the serving and returning strategies (from a placement perspective) executed by elite male and female players on grass courts. Such an investigation would contribute to a more holistic understanding of the importance of short points at Wimbledon, and provide valuable insight into how these points are typically won. Such analysis would also better inform coaches in their attempts to develop representative learning environments and effectively prepare players for grass court competitions (Reid et al., 2016).

Therefore, this study analyses Hawk-Eye ball-tracking data, to identify the most prevalent and the most effective (i.e. successful) serving and returning strategies executed by elite male and female players at Wimbledon, as well as establishing whether these strategies differ between winning and losing players.

2. Method

2.1. Data collection and sample

Institutional ethics approval was granted for this study, with access to the data provided by The All England Lawn Tennis Club, Wimbledon. Prior to the data collection, Hawk-Eye's technical operators calibrated the dimensions of each court and defined a right-handed court reference frame, with its origin at the base of the centre of the tennis net. The three-dimensional Cartesian coordinates, relative to the reference frame, of the ball-racket impact (i.e. ball contact location) and ball-court impact (i.e. ball landing location) were obtained for every stroke in 302 men's and 139 women's Wimbledon singles matches ($n = 71{,}812$ match-play points in total) contested between 2016 and 2018 on one of the six courts equipped with Hawk-Eye technology. This time period was selected, as it aligns with the data analysed in the key research that informed this study, and thus ensures that any findings can be directly informed by and interpreted alongside those from the previous research. In addition to the ball coordinate data, the following information was obtained for each stroke: year, match ID, point ID, server of the point, whether the point started with a first serve or a second serve, and stroke number (in the context of an individual point). Due to the nature of these data, reliability testing was not possible, however, the accuracy of Hawk-Eye ball-tracking technology has been independently validated, with a reported mean error of 2.6 mm, compared to a gold standard (Hawk-Eye, 2015a).

2.2. Data processing

Using a custom MATLAB (MathWorks, Natick, MA) script, several stages of data cleaning and error detection were undertaken. During stage one of this process,

coordinate data were assessed, such that all strokes performed by serving players should originate from one side of the net, and all strokes performed by returning players should originate from the opposite side of the net. Erroneous coordinates were then identified accordingly, and in stage two, all associated data (i.e. those within the same point) were removed. The following types of erroneous data were removed during stage two; i) instances when the ball contact location of a stroke and the ball landing location of that stroke were on the same side of the net, ii) instances when the ball contact location of a stroke was on the opposite side of the net to the ball landing location of the previous stroke, iii) instances when the ball contact location of a stroke was on the same side of the net as the ball contact location of the previous stroke, and iv) instances when the ball landing location of a stroke was on the same side of the net as the ball landing location of the previous stroke. Approximately 2.5% of match-play points (n = 1,795) were removed from the dataset accordingly.

Within stage three of the MATLAB script, serves, serve-returns, serve side (deuce or advantage court) and errors (unsuccessful strokes that landed in the net or out of court) were identified. At stage four, the ball landing coordinates of successful strokes were then analysed to establish which area (i.e. zone) of the court the ball landed in (see Figure 1). Note that right-handed players comprised an average of 85% of men's top 100 players and 92% of women's top 100 players each year between 2015 and 2017 (ATP, 2023; WTA, 2023). Therefore, serve zone is viewed from the perspective of a right-handed returner, whereby a serve to zone A is designed to elicit a forehand return, and a serve to zone D is designed to elicit a backhand return, irrespective of serve side. This "ABCD" zone labelling technique has been advised by O'Shannessy (2019) to better understand tennis

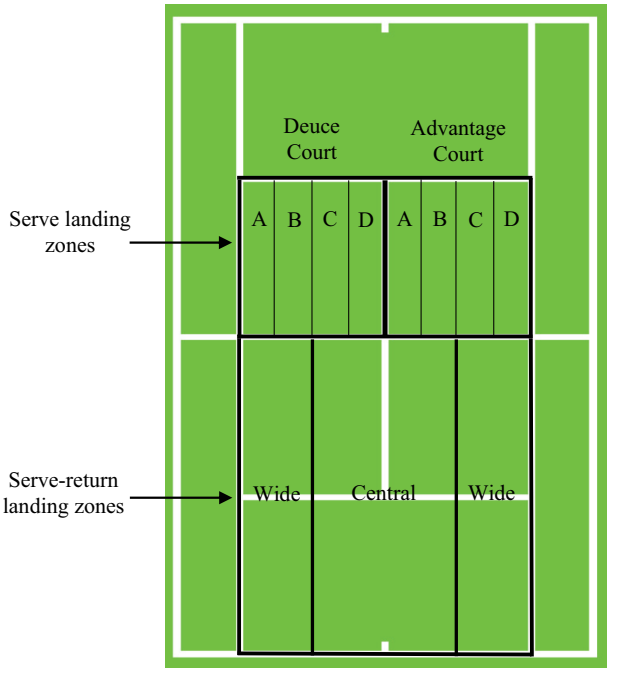

Figure 1. Serve and serve-return ball landing zones (i.e. strategies).

strategy. During stage five, stroke-level data were processed and aggregated to derive point-level data ($n = 53{,}328$ men's points, including 53,328 serves and 32,594 serve-returns, $n = 16{,}689$ women's points, including 16,689 serves and 11,884 returns). The point-level data included serve side, first or second serve, rally length, match winner, point winner (i.e. match winner or match loser, and serving player or returning player), and ball landing zone of both the serve and serve-return.

Ball landing locations are henceforth referred to as "serving strategies" for serve zones A, B, C and D, and "returning strategies" for wide and central serve-return zones. Additionally, deuce court first serves, deuce court second serves, advantage court first serves, and advantage court second serves are collectively referred to as "serve types", and corresponding serve-returns are referred to as "return types", for conciseness.

Note that all errors/missed strokes (i.e. those that landed in the net, wide of the sideline or behind the baseline) were recorded as having three-dimensional coordinates of (0,0,0), so it was not possible to establish their ball landing locations or infer any intended strategy. Accordingly, contextual understanding is paramount to the appropriate interpretation of results.

Serve-returns were originally analysed according to the combination of serve zone (A, B, C or D) and subsequent serve-return zone (A, B, C or D), i.e. creating a two-letter sequence for each point. However, serve-return results did not differ by serve zone, and statistical analysis (partitioned chi squares) showed that serve-return zone could be partially collapsed. Therefore, to increase sample size and aid interpretation, serve zone was omitted from the serve-return analysis and serve-return ball landing zones were reclassified as "wide" (previously zones A and D) and "central" (previously zones B and C), as shown in Figure 1.

The key performance indicators listed in Table 1 were calculated for men and women using the calculations presented. The calculations in Table 1 pertain to serve zone A and the central serve-return zone on deuce court first serve points, but results were calculated for all respective serve types, serve zones and, where appropriate, return types and serve-return zones.

Table 1. Definitions and calculations used to calculate the key performance indicators.

Key Performance Indicator	Definition/calculation
Serving strategy prevalence n	Total number of deuce court first serves to zone A
Serving strategy prevalence (%)	Number of deuce court first serves to zone A/number of successful deuce court first serves x 100
Serving strategy success rate (%)	Number of points won by the serving player following a deuce court first serve to zone A/number of deuce court first serves to zone A x 100
Serving strategies of winning players (%)	Number of deuce court first serves to zone A executed by match winners/total number of deuce court first serves executed by match winners x 100
Serving strategies of losing players (%)	Number of deuce court first serves to zone A executed by match losers/total number of deuce court first serves executed by match losers x 100
Returning strategy prevalence n	Total number of deuce court first serve-returns to central zones.
Returning strategy prevalence (%)	Number of deuce court first serve-returns to central zones/number of successful deuce court first serve-returns x 100
Returning strategy success rate (%)	Number of points won by the returning player following a deuce court first serve-return to central zones/number of deuce court first serve-returns to central zones x 100
Returning strategies of winning players (%)	Number of deuce court first serve-returns to central zones executed by match winners/total number of deuce court first serve-returns executed by match winners x 100
Returning strategies of losing players (%)	Number of deuce court first serve-returns to central zones executed by match losers/total number of deuce court first serve-returns executed by match losers x 100

2.3. Data analysis

All analyses were undertaken on men's and women's data, respectively. Due to the complexity of the data, two analysis methods, each explained below, were required.

First, upper and lower bounds for the prevalence of each serving strategy were calculated using sample size, based on 99% confidence intervals (Sullivan & LaMorte, 2016). These bounds were used to identify differences in the prevalence of serving strategies for each serve type.

Second, Chi-square analyses were undertaken to establish whether success rates differed between serving strategies (i.e. zones A, B, C and D), for each respective serve type. Where differences were identified, the overall chi-square was partitioned, as a form of post-hoc analysis (Bresnahan & Shapiro, 1966; Maxwell, 1961; Sharpe, 2015), to identify where the differences were (i.e. between which zones). Similarly, chi-square, and chi-square partitions when appropriate, were used to identify differences in the prevalence and success rates of returning strategies (i.e. wide and central zones), and whether serving and returning strategies differed between winning and losing players.

3. Results

3.1. Serving strategies: prevalence and success rates

Table 2 displays the prevalence (as a frequency and percentage) and success rate (percentage of points won by serving players) for each serve type and serving strategy (i.e. zones A, B, C and D) for men.

Table 2. Men's prevalence and success rate (i.e. percentage of points won by serving players) for each serving strategy.

Serve side	Serve and serve zone	Prevalence n (%)	Server success rate (%)
Deuce court	First serve		
	A	6985 (37.9%)[b]	76.1%[2]
	B	1860 (10.1%)[c]	61.7%[3]
	C	1847 (10.0%)[c]	64.8%[3]
	D	7751 (42.0%)[a]	77.9%[1]
	Second serve		
	A	1357 (14.5%)[c]	65.5%[1]
	B	1776 (19.0%)[c]	53.6%[3]
	C	3601 (38.4%)[a]	54.0%[3]
	D	2637 (28.1%)[b]	59.2%[2]
Advantage court	First serve		
	A	7078 (42.5%)[a]	73.4%[2]
	B	1341 (8.0%)[d]	63.1%[3]
	C	2196 (13.2%)[c]	60.5%[3]
	D	6045 (36.3%)[b]	79.7%[1]
	Second serve		
	A	1711 (19.3%)[b]	60.5%[1]
	B	1649 (18.6%)[b]	55.9%[2]
	C	3479 (39.3%)[a]	55.1%[2]
	D	2015 (22.8%)[b]	60.3%[1]

[a]Denotes the order of prevalence, based on 99% confidence intervals, from most prevalent serving strategy to least prevalent serving strategy, for each serve type, respectively.
[b]Denotes the order of success rate, based on Chi-square partitions, from most successful serving strategy to least successful serving strategy, for each serve type, respectively.

Table 2 shows differences in the prevalence of serving strategies for men. Confidence intervals (CI) calculated at a predetermined significance level of $p < 0.01$ revealed that on deuce court first serves, zone D was the most common serving strategy for men (prevalence = 42.0%, 99% CI [40.6%, 43.5%]), followed by zone A (prevalence = 37.9%, 99% CI [36.4%, 39.4%]). On advantage court first serves, zone A was the most common strategy (prevalence = 42.5%, 99% CI [41.0%, 44.0%]), followed by zone D (prevalence = 36.3%, 99% CI [34.7%, 37.9%]). On second serves, zone C was the most common serving strategy for men in the deuce court (prevalence = 38.4%, 99% CI [36.3%, 40.5%]) and advantage court (prevalence = 39.3%, 99% CI [37.2%, 41.4%]).

Table 2 also shows differences in men's serving strategy success rates, χ^2 (3, n = 53,328) = 1315.93, $p < .001$. Chi-square partitions revealed that for all four serve types, zones A and D exhibited higher success rates than zones B and C for men, χ^2 (1, n = 53,328) = 1306.91, $p < .001$. Furthermore, first serves to zone D exhibited higher success rates than first serves to zone A in the deuce court: χ^2 (1, n = 14,736) = 6.48, $p < .05$, and advantage court: χ^2 (1, n = 13,123) = 66.88, $p < .001$. On deuce court second serves, zone A exhibited a higher success rate than zone D, χ^2 (1, n = 3994) = 14.76, $p < .001$.

Table 3 displays the prevalence (as a frequency and percentage) and success rate (percentage of points won by serving players) for each serve type and serving strategy (i.e. zones A, B, C and D) for women.

Table 3 shows differences in the prevalence of serving strategies. Confidence intervals calculated at a predetermined significance level of $p < 0.01$ indicated that on deuce court first serves, zones A (prevalence = 33.5%, 99% CI [30.7%, 36.3%]) and D (prevalence = 36.0%, 99% CI [33.3%, 38.7%]) were the most common serving

Table 3. Women's prevalence and success rate (i.e. percentage of points won by serving players) for each serving strategy.

Serve side	Serve and serve zone	Prevalence n (%)	Server success rate (%)
Deuce court	First serve		
	A	1937 (33.5%)[a]	71.0%[1]
	B	879 (15.2%) [b]	59.5% [2]
	C	884 (15.3%)[b]	58.6%[2]
	D	2081 (36.0%)[a]	72.5%[1]
	Second serve		
	A	378 (13.0%)[b]	59.0%[1]
	B	593 (20.4%)[b]	51.4%[2]
	C	1206 (41.5%)[a]	49.3%[2]
	D	732 (25.2%)[b]	55.1%[1]
Advantage court	First serve		
	A	2014 (38.7%)[a]	67.6%[2]
	B	722 (13.9%)[c]	60.4%[3]
	C	939 (18.1%)[c]	57.0%[3]
	D	1523 (29.3%)[b]	73.9%[1]
	Second serve		
	A	509 (18.2%)[b]	53.2%[1]
	B	658 (23.5%)[b]	46.2%[2]
	C	1091 (39.0%)[a]	52.1%[1]
	D	543 (19.4%)[b]	53.6%[1]

[a]Denotes the order of prevalence, based on 99% confidence intervals, from most prevalent serving strategy to least prevalent serving strategy, for each serve type, respectively.
[b]Denotes the order of success rate, based on Chi-square partitions, from most successful serving strategy to least successful serving strategy, for each serve type, respectively.

strategies for women. On advantage court first serves, zone A was the most common strategy (prevalence = 38.7%, 99% CI [35.9%, 41.5%]), followed by zone D (prevalence = 29.3%, 99% CI [26.3%, 32.3%]). On second serves, zone C was the most common serving strategy for women, in the deuce court (prevalence = 41.5%, 99% CI [37.8%, 45.1%]) and advantage court (prevalence = 39.0%, 99% CI [35.1%, 42.8%]).

Table 3 also shows differences in women's serving strategy success rates, χ^2 (3, n = 16,689) = 304.87, $p < .001$. Chi-square partitions revealed that zones A and D exhibited higher success rates than zones B and C for deuce court first serves, χ^2 (1, n = 5781) = 91.10, $p < .001$, deuce court second serves, χ^2 (1, n = 2909) = 11.16, $p < .001$, and advantage court first serves, χ^2 (1, n = 5198) = 71.69 $p < .001$. Within this, zone D exhibited a higher success rate than zone A for advantage court first serves, χ^2 (1, n = 3537) = 15.49, $p < .001$. For advantage court second serves, zone B exhibited lower success rates than zones A, C and D, χ^2 (1, n = 2801) = 8.59, $p < .01$.

3.2. Serving strategies executed by winning and losing players

Figure 2 displays, for each serve type, the percentage of serves executed to zones A, B, C and D by winning and losing male players, respectively (i.e. serving strategies used by winning and losing male players).

Figure 3 displays, for each serve type, the percentage of serves executed to zones A, B, C and D by winning and losing female players, respectively (i.e. serving strategies used by winning and losing female players).

3.3. Returning strategies: prevalence and success rates

Table 4 displays men's prevalence and success rate (i.e. percentage of points won by returning players) for each returning strategy (wide and central), for all four return types (i.e. deuce and advantage court first and second serve-returns).

Chi-square analysis revealed that for all return types, male players hit more serve-returns to central zones (B and C) than wide zones (A and D), χ^2 (3, n = 32,594) = 131.61, $p < .001$, and chi-square partitions showed that this difference was greater on first serve-returns than second serve-returns, χ^2 (1, n = 32,594) = 112.31, $p < .001$. For all return types, serve-returns to wide zones elicited higher success rates for returning players than serve-returns to central zones, χ^2 (3, n = 32,594) = 243.82, $p < .001$; within this, chi-square partitions revealed that second serve-returns elicited higher success rates than first serve-returns, χ^2 (1, n = 32,594) = 242.60, $p < .001$.

Table 5 displays women's prevalence and success rate (i.e. percentage of points won by returning players) for each returning strategy (wide and central), for all four return types.

Table 5 shows that for all return types, female players hit more serve-returns to central zones (B and C) than wide zones (A and D), χ^2 (3, n = 11,884) = 90.56, $p < .001$, and that this difference was greater on first serve-returns than second serve-returns, χ^2 (1, n = 11,884) = 88.22, $p < .001$. For all return types, serve-returns to wide zones elicited higher success rates than serve-returns to central zones, χ^2 (3, n = 11,884) = 144.22, $p < .001$; within this, second serve-returns elicited higher success rates than first serve-returns, χ^2 (1, n = 11,884) = 143.73, $p < .001$.

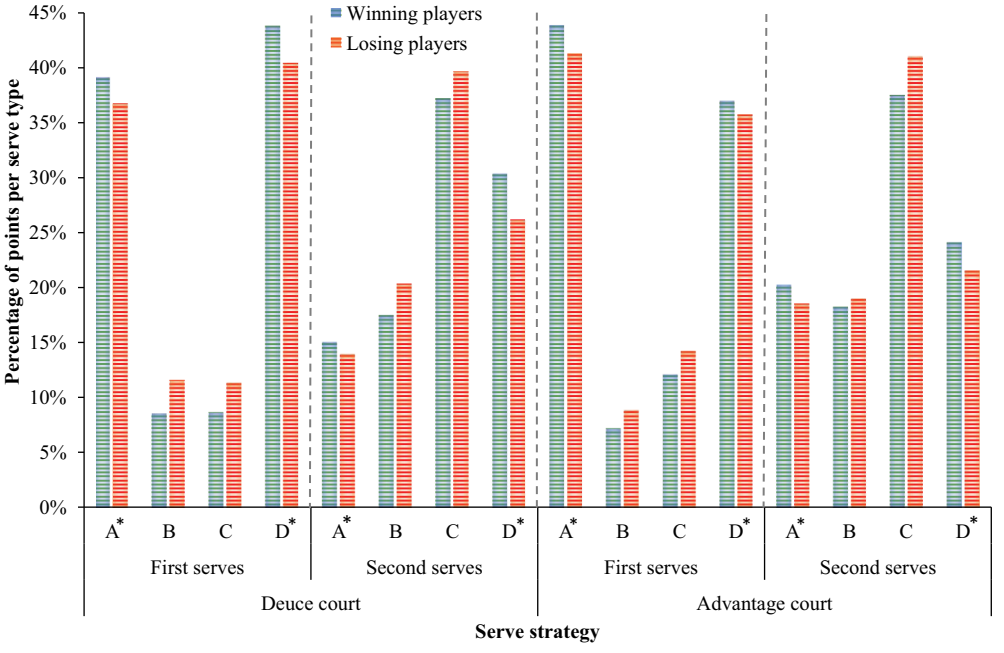

Figure 2. Serving strategies executed by winning and losing male players. * Zones to which winning male players hit a significantly higher percentage of serves than losing players ($p<0.001$). Results revealed that serving strategies differed between winning and losing male players, χ^2 (3, n=53,328) =169.01, $p<.001$. For all serve types, winning male players executed a greater percentage of their serves to zones A and D (lateral zones) than losing male players, whereas losing players executed a greater percentage of their serves to zones B and C (central zones) than winning players, χ^2 (1, n=53,328)=166.82, $p<.001$.

3.4. Returning strategies executed by winning and losing players

Figure 4 shows, for each return type, the percentage of serve-returns executed to wide and central zones by winning and losing male players, respectively (i.e. returning strategies used by winning and losing male players).

Figure 5 shows, for each return type, the percentage of serve-returns executed to wide and central zones by winning and losing female players, respectively (i.e. returning strategies used by winning and losing female players).

4. Discussion

This study aimed to identify the most prevalent and effective serving and returning strategies executed by men and women at Wimbledon, and establish associated winner-loser differences. The key findings, discussed below, enhance our understanding of players' tactical strategies, and in turn, can inform players' planning and preparation for the grass court season.

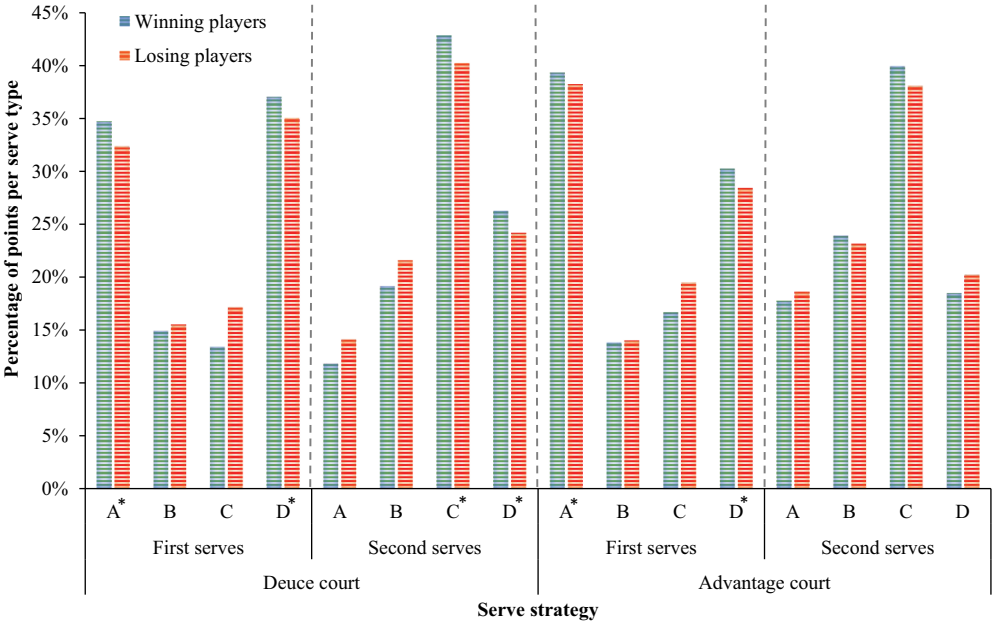

Figure 3. Serving strategies executed by winning and losing female players. * Zones to which winning female players hit a significantly higher percentage of serves than losing female players ($p<0.05$). Results revealed that serving strategies differed between winning and losing female players, χ^2 (3, n=16,689)=10.07, $p<.05$. Chi-square partitions showed that for deuce and advantage court first serves, winning players executed a greater percentage of their serves to zones A and D (i.e. lateral zones) than losing players, deuce court first serves: χ^2 (1, n=5781)=12.79, $p<.001$, advantage court first serves: χ^2 (1, n=5198)=5.33, $p<.05$. For deuce court second serves, winning players executed a greater percentage of serves to zones C and D than losing players, χ^2 (1, n=2909)=7.29, $p<.01$. No differences were observed for advantage court second serves, χ^2 (3, n=2801)=2.23, $p>.05$.

Table 4. Men's prevalence and success rate for each returning strategy.

		Return prevalence n (%)		Returner success rate (%)	
Serve side	Return	Wide zones (A & D)	Central zones (B & C)*	Wide zones (A & D)^	Central zones (B & C)
Deuce court	First serve-return	3025 (30.9%)	6776 (69.1%)@	52.0%	43.7%
	Second serve-return+	2456 (34.6%)	4642 (65.4%)	61.8%	52.2%
Advantage court	First serve-return	2749 (30.5%)	6251 (69.5%)@	51.9%	44.7%
	Second serve-return+	2551 (38.1%)	4144 (61.9%)	62.9%	50.1%

*Significantly more prevalent than wide zones ($p < .001$).
@Significantly more prevalent than second serve-returns ($p < .001$).
^Significantly higher success rates than central zones ($p < .001$).
+Significantly higher success rates than first serve-returns ($p < .001$).

4.1. Serving strategies: prevalence and success rates (Tables 2 and 3)

For players of both sexes, the most prevalent first serve strategies were zones A and D, and the most prevalent second serve strategy was zone C, reflecting the results of Mecheri et al. (2016) and Martinez-Gallego et al. (2021, within doubles matches). Zones A and D were the most effective serving strategies, eliciting the highest success rates for serving players, for all serve types for men and women, except

Table 5. Women's prevalence and success rate for each returning strategy.

		Return prevalence n (%)		Returner success rate (%)	
Serve side	Return	Wide zones (A & D)	Central zones (B & C)*	Wide zones (A & D)^	Central zones (B & C)
Deuce court	First serve-return	1117 (29.5%)	2669 (70.5%)@	55.1%	45.1%
	Second serve-return+	865 (37.3%)	1453 (62.7%)	67.5%	54.9%
Advantage court	First serve-return	1061 (30.3%)	2436 (69.7%)@	56.5%	45.6%
	Second serve-return+	894 (39.2%)	1389 (60.8%)	67.0%	55.2%

*Significantly more prevalent than wide zones ($p<0.001$).
@Significantly more prevalent than second serve-returns ($p<0.001$).
^Significantly higher success rates than central zones ($p<0.001$).
+Significantly higher success rates than first serve-returns ($p<0.001$).

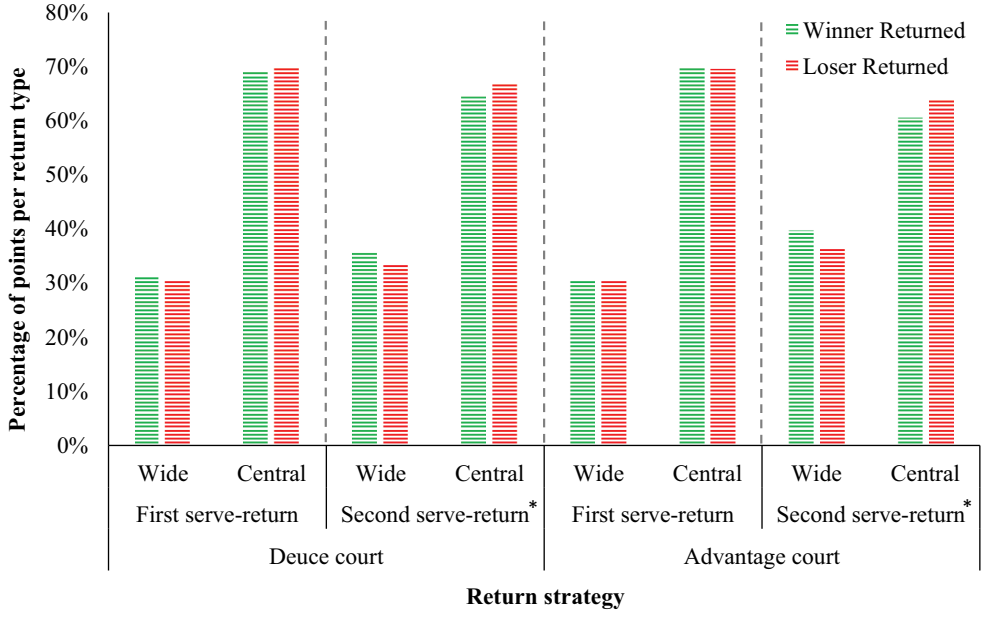

Figure 4. Returning strategies executed by winning and losing male players. *Return type whereby winning male players hit a higher percentage of serve-returns to wide zones than losing male players ($p<0.05$). Analysis revealed differences in the returning strategies executed by winning and losing male players, χ^2 (1, n=32,594)=6.78, $p<.01$. Winning players executed a higher percentage of second serve-returns to wide zones compared to losing players, whereas losing players executed a higher percentage of second serve-returns to central zones than winning players, deuce court: χ^2 (1, n=7098) =4.92, $p<.05$, advantage court: χ^2 (1, n=6695)=7.51, $p<.01$. No winner-loser differences were identified for first serve-return strategies.

advantage court second serves for women. This is likely because serves to zones A and D are typically more difficult for returning players to retrieve (Martinez-Gallego et al., 2021), as they are required to move a greater distance to reach the ball, particularly when spin is applied to the serve, as the ball constantly moves further away from the returner (van de Braam & Crespo, 2014; Shelton et al., (2016)). Logically, it could be expected that, if zones A and D are more successful serving strategies than zones B and C, players would execute most first and second serves to zones A and D. However, zones A and D are closer to the lateral edges of

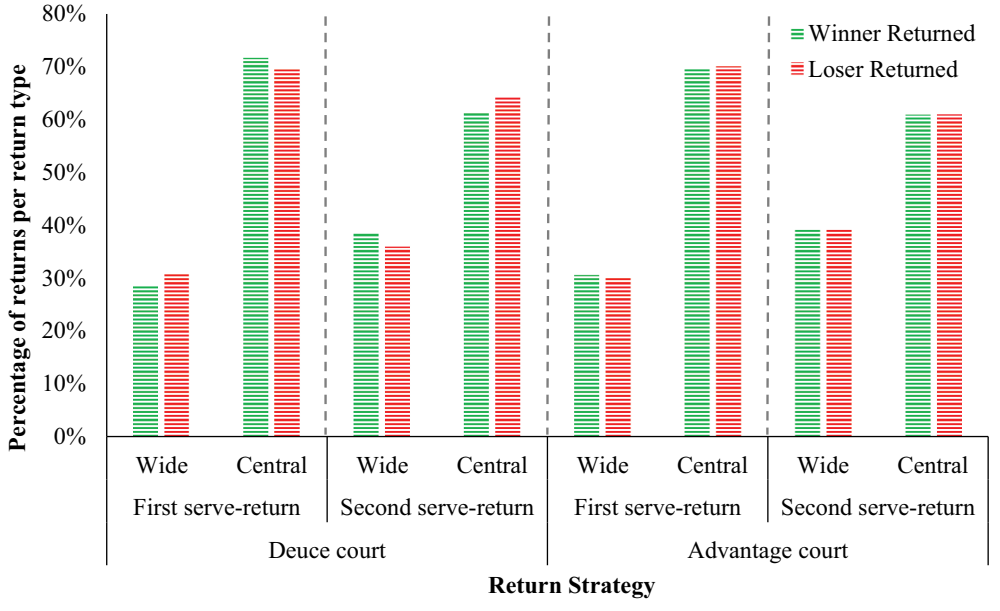

Figure 5. Returning strategies executed by winning and losing female players. Analysis revealed no differences in the returning strategies executed by winning and losing female players, χ^2 (1, n=11,884) =0.003, p>.05.

the service box than zones B and C, and are therefore more risky strategies to attempt (Ruder, 2019). Additionally, when a player misses a first serve, they can attempt a second serve (i.e. a second chance to execute a successful serve), but the consequence of missing a second serve is the immediate loss of a point (Antoun, 2007; Martinez-Gallego et al., 2021). Therefore, it is understandable that players take more risk on first serves by aiming to zones A and D more often, as they are more likely to win the point if the serve lands in, and they can attempt a second serve if they miss. On seconds serves, the high prevalence of zone C is understandable, as, despite its low success rate compared to zones A and D, it is more central and therefore safer to aim for when the consequence of missing is losing the point (Ruder, 2019). Additionally, Mecheri et al. (2016) reported that most players prefer to hit second serves to their opponent's backhand, as it is usually considered the weaker stroke (Martinez-Gallego et al., 2021); hitting a second serve to zone C means that a right-handed returner is more likely to hit a backhand serve-return than a forehand serve-return. In contrast, the other central and therefore relatively safe second serve zone (zone B), is more likely to elicit a forehand serve-return, which is the preferred and stronger stroke for most elite players (Martin-Lorente et al., 2017).

4.2. Serving strategies executed by winning and losing players (Figures 2 and 3)

For all serve types, winning male players hit a higher percentage of their serves to zones A and D than losing male players; correspondingly, losing players hit a higher percentage

to zones B and C than winning players. As mentioned, serves to zones A and D elicited higher success rates than serves to zones B and C for men (see Table 2), so the winner-loser differences revealed here are logical, demonstrating that male players who are more accurate with their first and second serves (i.e. hitting to zones A and D) more often than their opponent, are more likely to win the match. These findings support previous assertions that the serve is an important stroke in elite tennis (Martinez-Gallego et al., 2021; Mecheri et al., 2016; Klaus et al., 2017), and highlight the importance of accuracy for male players when serving on grass courts. The same pattern was evident for women's first serves, with winning players hitting a higher percentage of their first serves to zones A and D than losing players. However, for second serves, winner-loser differences were only identified in the deuce court, whereby winning female players served more second serves to zones C and D than losing players. This likely indicates that winning female players attempted to exploit their opponent's backhand serve-return more often than losing players on deuce court second serves. However, zone C was a relatively unsuccessful strategy for deuce court second serves (see Table 3), so it is not clear why it was so prevalent for women, particularly for winning players. Perhaps female players are unaware of the relatively low success rate of zone C, believing that eliciting a backhand serve-return is favourable to eliciting a forehand serve-return, which is not always the case (Antoun, 2007). Alternatively, they may be aware of it, but still prefer to execute a seemingly safer serving strategy than risk a double fault by aiming for a more lateral zone. Either way, these results suggest it may be advisable for women to spread the distribution of their deuce court second serves more. In line with this, Nigel Sears, former coach of three WTA top 10 singles players, highlighted the importance of accuracy and unpredictability of women's second serves, stating that a strong second serve keeps the opponent constantly guessing (Antoun, 2007), an observation supported by Ruder (2019).

The winner-loser differences identified in men's and women's serving strategies were small (between 1% and 4%, Figures 2 and 3), and could therefore appear insignificant, but it is important to note that this is not the case. The outcome of a tennis match can be decided by tiny margins (O'Shannessy, 2017b); it is even possible to lose more points than an opponent in a match and still win, a phenomenon known as the Quasi-Simpson paradox (Lisi et al., 2019). This should help demonstrate how small differences between players' strategies, such as those revealed here, can influence match outcome and therefore be crucial.

4.3. Returning strategies: prevalence and success rates (Tables 4 and 5)

In terms of returning strategies, men and women hit more serve-returns to central zones (B and C) than to wide zones (A and D) for all return types. This may be because serve-returns to central zones limit the tactical options of the server on their second shot, by reducing the space (i.e. angles) available for them to attack, making it more difficult for them to open up the court and/or finish the point quickly (Antoun, 2007; Gillet et al., 2009). The prevalence of central zones on serve-returns may also be due to the lower risk associated with these zones compared to wide zones. As with serve zones, serve-return zones A and D (i.e.

wide zones) are closer to the lateral edges of the court than zones B and C, which are central and therefore less risky to target (Ruder, 2019).

Results also revealed that, for all men's and women's return types, players hit a higher percentage of serve-returns to central zones on first serve-returns than second serve-returns, and won a higher percentage of points by hitting serve-returns to wide zones than central zones. Additionally, players of both sexes won a lower percentage of points when returning first serves than when returning second serves. These results replicate those reported in Gillet et al. (2009) analysis of men's clay court match-play, and can be explained theoretically using ecological dynamics. From a serving perspective, an effective serve allows the server to destabilise the dynamic equilibrium of the point and gain an immediate tactical advantage (O'Donoghue & Brown, 2008). Consequently, elite players often use their serve (predominantly their first serve) as a tactical weapon to force their opponent to perform a difficult serve-return (Antoun, 2007). So, first serve-returns are typically performed in a reactive manner, with the priority of getting the ball back into play (Pretorius & Boucek, 2020). Under these extreme constraints, first serve-returns are less likely to trouble the server, and often leave the returner at a tactical disadvantage in the point; partly explaining why players won a lower percentage of first serve-return points than second serve-return points. Additionally, if the primary goal on first serve-returns is simply to hit the ball back into court, rather than attempting to hit a winner or force the server to commit an error, which is considered difficult and risky (Bollettieri, 2015), then central zones are the safest to target. This may be why players executed a higher percentage of first serve-returns to central zones than second serve-returns.

The higher success rates achieved by players returning second serves compared to returning first serves and the higher percentage of strokes hit to wide zones on second serve-returns compared to first serve-returns could also be explained by the tendency for elite players to opt for a faster first serve, slower second serve strategy (Barnett et al., 2008; Pollard, 2008). Slower second serves are hit more conservatively than first serves (Antoun, 2007), so, from a returning perspective, second serves afford the returner more time to prepare for their stroke (Gillet et al., 2009). Therefore, on second serve-returns, as proposed by Fitzpatrick et al. (2021), players are more likely to be able to be position themselves optimally to execute an attacking and accurate serve-return to a wide zone, placing time and positional constraints on the serving player, and potentially creating a perturbation that could lead to the returning player winning the point. In contrast, faster first serves impose greater time constraints on the returning player, restricting the time available to react and perform a serve-return, resulting in a higher likelihood of the serving player winning the point.

4.4. Returning strategies executed by winning and losing players (Figures 4 and 5)

In terms of winner-loser differences in returning strategies, winning male players hit a higher percentage of second serve-returns to wide zones than losing male players. This indicates that winning male players were able to recognise and exploit their

opponent's weaker second serves, executing accurate serve-returns to wide zones, more often than losing players. In turn, this immediately exposes the server to positional constraints, affording the returner the tactical advantage early in the point. This winner-loser difference supports the assertion that players who can use their opponent's weak second serve to their own advantage have a major asset in their arsenal (Gilbert & Jamison, 2013).

No winner-loser differences were identified for women's returning strategies, or for men's first serve-returns. This could imply that returning strategies are not important for women and are only somewhat important for men; however, Fitzpatrick et al. (2021) demonstrated the critical importance of the serve-return for winning matches in elite grass court tennis. So, it is possible that other factors or combinations of factors linked to the serve-return, rather than accuracy (i.e. zone), differentiate winning and losing players; these could include serve-return speed, serve-return spin (Gillet et al., 2009), and/or more specific serve-return accuracy measures than those analysed in this study.

4.5. Practical application

An important strength of this research is the reporting of "big data" findings in a coach-friendly manner, through the translation of complex Hawk-Eye coordinate data into easy-to-interpret, zone-based serving and returning strategies. This zone-based approach is aligned with commonly used, tennis-specific terminology and was therefore adopted to facilitate coaches' understanding of the results and ability to implement the associated practical applications.

As highlighted by Reid et al. (2016), investigating Hawk-Eye data in tennis is crucial for enhancing specificity (the ability to reproduce the characteristics of competition during training), a key principle in the design and implementation of evidence-based training programmes (Martinez-Gallego et al., 2021). Accordingly, coaches can use the findings from this study to improve the specificity and representative design of players' grass court training, ensuring practices are sufficiently reflective of match-play. For example, coaches could ensure that the sex-specific serving strategies that are most successful are afforded more time and emphasis during training. Crucially, however, coaches of elite players should also consider how the findings and associated interpretation can be tailored to their individual players. For example, some coaches of elite male players may wish to prioritise enhancing their player's second serve-return ability, underpinned by the knowledge that executing more second serve-returns to wide areas is a differentiating factor in the men's game. However, depending on a player's current strengths and weaknesses, the same finding may lead other coaches to focus on developing their player's second serve, with the aim of reducing the opportunities afforded to opponents to direct serve-returns to wide areas. The results of this study can also be used to inform players' tactical preparation for specific grass court matches, alongside opposition data analysis, and for grass court events, more generally.

4.6. Limitations

Only one indicator of strategy – ball landing location – was analysed. Despite having been shown to influence the probability of winning a point (Gillet et al., 2009), ball speed and ball

spin rate were not measured. Serve-volley analysis was also not undertaken here, due to limitations of the dataset. Future research investigating serve-volley strategies would be beneficial, as the tactic is thought to be successful, particularly on grass courts (O'Shannessy, 2020). Other aspects that can influence performance, for example, players' ATP/WTA rankings (Reid, McMurtrie & Crespo, 2016), and situational variables such as round of competition and score-line (Cui et al., 2020), were not considered here, but their inclusion in subsequent research may provide additional contextual insight. Of particular interest might be the identification of the serving and returning strategies adopted on game/break points compared to "normal" points, and whether *closely contested* matches occur more often in the latter rounds of tournaments. Finally, future serve and serve-return related studies could aim to stratify data by handedness, as serving strategy has been shown to differ between left- and right-handed players (Loffing et al., 2009).

5. Conclusion

This study has provided new insights into the serving and returning strategies executed in elite grass court tennis. Male and female players preferred to hit first serves to the lateral edges of the service box, putting their opponent under time and positional pressure. On second serves, players typically opted for a safer strategy, while potentially trying to elicit a backhand serve-return. Central zones were the most common returning strategies for both sexes, particularly on first serve-returns, possibly because central zones present less risk than wide zones. Despite this, wide zones elicited more success for returning players than central zones, particularly on second serve-returns, likely due to the additional time afforded to returning players to prepare for their stroke, compared to first serve-returns. Male winning players forced their opponents into difficult positions more often than losing male players, hitting a comparatively higher percentage of their serves and serve-returns to lateral areas; female winning players demonstrated this behaviour only on first serves.

These results contribute to a growing body of research analysing Hawk-Eye's ball-tracking data in elite tennis and provide greater context around the results reported in previous studies (e.g. Fitzpatrick et al., 2021; Mecheri et al., 2016), enhancing our understanding of how matches are won at Wimbledon. Coaches can use our findings to enhance the specificity and representative design of players' grass court training, ensuring practices reflect match-play where appropriate.

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