Journal of Sports Sciences
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/rjsp20

A notational analysis of elite tennis strategy

Peter O'Donoghue [a] & Billy Ingram [a]
[a] School of Applied Medical Science and Sports Studies, University of Ulster, Jordanstown, Co. Antrim BT37 0QB, UK
Version of record first published: 01 Dec 2010.

To cite this article: Peter O'Donoghue & Billy Ingram (2001): A notational analysis of elite tennis strategy, Journal of Sports Sciences, 19:2, 107-115

To link to this article: http://dx.doi.org/10.1080/026404101300036299

Journal of Sports Sciences, 2001, **19**, 107–115

A notational analysis of elite tennis strategy

PETER O'DONOGHUE* and BILLY INGRAM

School of Applied Medical Science and Sports Studies, University of Ulster, Jordanstown, Co. Antrim BT37 0QB, UK

Accepted 11 September 2000

A notational analysis of singles events at all four Grand Slam tournaments between 1997 and 1999 was conducted to determine the influence of the sex of the player and court surface on elite tennis strategy. Rallies of 7.1 ± 2.0 s in women's singles were significantly longer than those in men's singles (5.2 ± 1.8 s; $P < 0.001$). Rallies of 6.3 ± 1.8 s at the Australian Open, 7.7 ± 1.7 s at the French Open, 4.3 ± 1.6 s at Wimbledon and 5.8 ± 1.9 s at the US Open were recorded. Rallies were significantly longer at the French Open than at any other tournament ($P < 0.05$) and significantly shorter at Wimbledon than at any other tournament ($P < 0.05$). In women's singles, 52.8 ± 12.4% of points were baseline rallies, significantly more than in men's singles (28.6 ± 19%; $P < 0.001$). The proportion of baseline rallies played at the French Open (51.9 ± 14.2% of points) was significantly greater than at the Australian Open (46.6 ± 12.5%), Wimbledon (19.7 ± 19.4%) and the US Open (35.4 ± 19.5%; $P < 0.05$). The results show that both the sex of the player and surface of the court have a significant influence on the nature of singles tennis at Grand Slam tournaments.

Keywords: elite performers, notational analysis, tennis strategy.

Introduction

Tennis is a dynamic and complex game in which players repeatedly make decisions on positioning and shots. Players plan strategies to maximize their chances of winning a match based on knowledge of their own strengths and weaknesses as well as those of their opponent. The strategy also takes into consideration environmental factors, such as weather conditions and court surface. Various authors have investigated elite tennis strategy using timing factors, shot details (Hughes and Clarke, 1995), positional play, distance covered (Underwood and McHeath, 1977) and point profiles (O'Donoghue and Liddle, 1998b).

A detailed analysis of strategy in men's singles rallies at the 1992 Australian Open and Wimbledon Grand Slam tournaments revealed mean rallies of 4.72 and 2.50 s respectively (Hughes and Clarke, 1995). The frequencies of service winners and aces were similar for the two tournaments, but 11% more serves were returned at the Australian Open than at Wimbledon. Errors, rather than winners, were found to be the main cause of rallies ending at both tournaments. Hughes and Clarke also found a tendency of positioning to the left at the Australian Open, where the slower surface provides time for players to run around their backhand. Further work was recommended to investigate tennis strategy for males and females, different court surfaces, stages of match-play and standards of play (Hughes and Clarke, 1995).

The US Open moved from the grass courts of Forrest Hills to the hard courts of Flushing Meadow in 1978 and the Australian Open moved from the grass surface of Kooyong to the synthetic grass surface of Melbourne Park in 1986. Wimbledon remains a grass court tournament and the French Open is still played on the clay of Roland Garros. Therefore, the four Grand Slam tournaments are now played on different surfaces. A study of the strategy of elite male and female players at each tournament would provide valuable information for aspiring players and their coaches.

The aim of this study was to determine whether the sex of the player and the surface of the court have an effect on the strategies of elite tennis players in singles events at Grand Slam tournaments. A notational analysis of elite tennis strategy in Grand Slam tournaments was undertaken between May 1997 and January 1999.

* Author to whom all correspondence should be addressed.

Methods

Research design

This study was a quantitative analysis of tennis based on timing factors and point profiles. Objective details of points were entered into a computerized data collection system facilitating automatic analysis. The system was used to analyse individual matches and produce a spreadsheet for statistical analysis.

Matches

Sections of 252 Grand Slam tournament singles matches from terrestrial and satellite television coverage were recorded and analysed using a specially designed computerized notational analysis system for tennis. Only matches that were broadcast live were recorded to avoid introducing highlights of tennis that might contain a disproportionately high number of service breaks. The matches included in the current study were from the third round to the final using the criteria of Hughes and Clarke (1995); an elite player at a given tournament must have already beaten two fellow professionals during that tournament. The total data captured was 366 h and 6 min of coverage containing 37,229 points. To ensure further that each match section used was representative of Grand Slam tennis, all matches in which less than 100 points were recorded were excluded from the study. This reduced the number of matches analysed from 252 to 175; these lasted 313 h and 13 min and contained a total of 31,558 points. Table 1 summarizes the data analysed.

Computerized notational analysis system

The computerized notational analysis system for tennis was developed by the authors and used to record details of matches included within the study. The system recorded match identification details as well as details of each point in the section of the match being entered. The match identification details included the player's sex, tournament (which indicated the surface), the players involved, the player who served first and the score at the start of that section of the match. Recording the sex of the players allowed the system to determine whether the match was the best of three or five sets and recording the tournament allowed the system to determine whether or not there was a tie break in the final set (this is currently the case at the US Open only). Once the match identification details had been entered, the system allowed details of each point to be entered. The score and serving player at the beginning of each point were determined automatically from the details of the previous point. The following details were recorded for each point:

- score (sets, games and points) at the start of the point;
- serving player;
- whether the point emanated from a first or second service;
- timing details (inter-serve times, rally time and inter-point time);
- number of shots played in the rally;
- type of point (ace, double fault, serve winner, return winner, server to net first, receiver to net first and baseline rally);
- outcome of point (winning player and whether point was won with a winner or by an error on the part of the opponent).

As successive points were entered, the system automatically updated the score and, where necessary, the serving player. The system also allowed non-scoring points, such as 'lets', to be identified. If a penalty point was awarded, the system allowed the score at the beginning of the next point to be altered accordingly.

The user entered data into the computerized system while observing a video-recording of a tennis match. The system executes on any IBM-compatible computer and runs under the DOS operating system. A Siemens Nixdorf 486 Notepad computer was used for the current study. The data relating to each point were objective, in that a point was deemed to have ended at the instant at which it ended according to the rules of lawn tennis. An ace was a winning serve that the opponent did not touch with the racket. Other winning serves, where the server won the point without having to play a second shot, were recorded as serve winners. Serve return winners were winning service returns that the server did not strike with the racket. A player was deemed to have approached the net if he or she had

Table 1. The data analysed from the four Grand Slam tournaments

	Matches played	Players involved	Volume (h:min)	Rallies analysed
Women's singles				
Australian Open	18	13	23:34	2472
French Open	14	13	21:30	2132
Wimbledon	13	16	18:29	1892
US Open	23	20	35:08	3433
Men's singles				
Australian Open	24	25	43:14	4453
French Open	22	24	45:44	4273
Wimbledon	26	26	51:13	5392
US Open	35	32	74:20	7511

Table 2. Inter-observer reliability of timing factors

Variable	Heteroscedasticity correlation	Heteroscedasticity correlation of natural log	95% Limits of agreement	ICC
Length of rally	−0.574	−0.900	−0.006 ± 0.062	0.997
Inter-serve time	0.126	−0.233	0.003 ± 0.017	0.998
Inter-point time	0.304	0.235	−0.001 ± 0.011	0.995

Abbreviation: ICC = intra-class correlation.

Table 3. Intra-observer reliability of timing factors

Variable	Heteroscedasticity correlation	Heteroscedasticity correlation of natural log	95% Limits of agreement	ICC
Length of rally	−0.708	−0.893	−0.005 ± 0.020	0.999
Inter-serve time	0.029	−0.261	−0.001 ± 0.007	0.999
Inter-point time	0.274	0.226	−0.001 ± 0.006	0.998

Abbreviation: ICC = intra-class correlation.

crossed the service line when shots were still to be played in the rally. Therefore, a player hitting a winner and following it into the net as if it were an approach shot did not count as a net point. Similarly, a player at the net was deemed to have retreated once they had crossed the service line in the direction of the baseline and there were still shots to play in the rally. No distinction was made between forced and unforced errors, reducing the risk of subjective opinion influencing the data entered.

Reliability of timing factors

The timing factors used were rally times, inter-serve times and inter-point times. The reliability of the method was established in an inter- and intra-observer reliability study using video-recorded sets of tennis from eight different matches containing a total of 923 points. The eight matches consisted of a women's singles match and a men's singles match from each of the four tournaments. For both inter- and intra-observer reliability, the eight matches were entered and analysed; values for rally time, inter-serve time and inter-point time were compared. Heteroscedasticity correlations were computed for all timings as well as their natural logarithms. Heteroscedasticity was not deemed to be a problem and hence all reliability assessments were assessed using Bland and Altman's 95% limits of agreement (Bland and Altman, 1986; Atkinson and Neville, 1998). In addition, we decided to express relative reliability as an intra-class correlation coefficient. Tables 2 and 3 show that the measurement of timing factors achieved good relative reliability within the inter- and intra-observer reliability studies respectively.

Reliability of strategy data

The data entered during the reliability study of timing factors were also analysed in terms of the strategy data. The inter- and intra-observer reliability study examined the data recorded for each of the 923 points so that kappa statistics could be computed (Table 4). The figures show 'very good' agreement (Altman, 1991) with no data recording errors for the type of point, end type (winner or error) or winning player.

Statistical analysis

The data were loaded into SPSS to allow inferential statistical analysis procedures to be applied. Percentages of point categories were analysed using non-parametric statistical procedures. Kruskal Wallis *H*-tests were used to compare the four tournaments. Where significant differences were revealed between tournaments, Mann-Whitney *U*-tests were used to compare pairs of tournaments with a Bonferonni adjustment applied to the α level to reduce the probability of a Type I error. Mann-Whitney *U*-tests were used to compare men's and women's singles. Non-parametric procedures were

also applied to the timing factors because of the heteroscedastic nature of these variables. The overall analysis involved many individual tests at a 95% confidence level. This was justified for two reasons. First, the individual comparisons were important aspects of Grand Slam tennis to investigate in their own right. Secondly, the data comprised details of 175 tennis matches recorded over 2 years, during which there was a total of 496 Grand Slam tournament matches from the third round to the final.

Table 4. Reliability of strategy data (kappa)

Measure	Inter-observer reliability	Intra-observer reliability
First or second service	0.989	0.994
Point type	1.000	1.000
End type (winner or error)	1.000	1.000
Point winner	1.000	1.000

Results

Timing factors

Figure 1 shows the lengths of rallies and Fig. 2 shows the number of shots played per second for the different singles games. The sex of the player ($z = 5.9$, $P < 0.001$) and the surface of the court ($\chi^2_3 = 57.2$, $P < 0.001$) had a significant influence on rally time. Sex ($z = 6.7$,

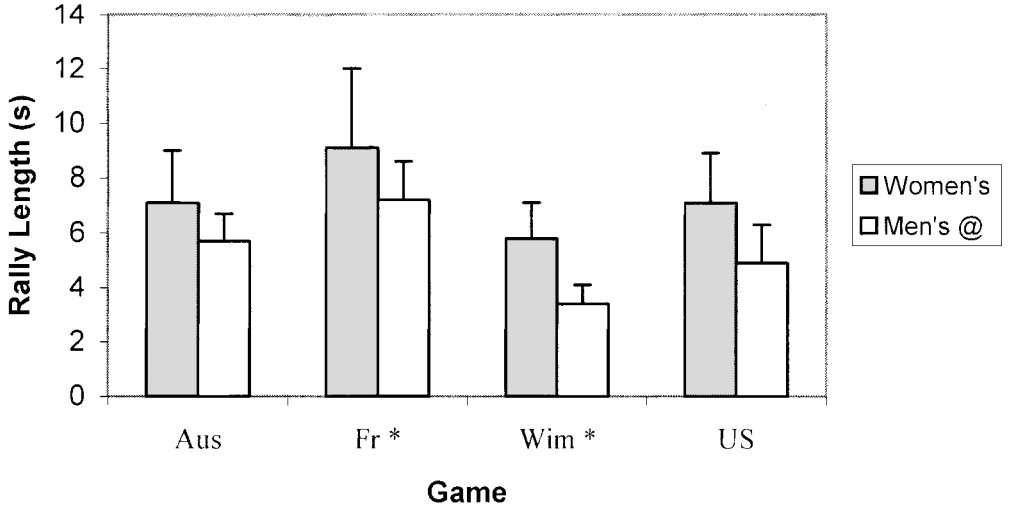

Fig. 1. Length of rallies for different singles games. * Significantly different to all other tournaments ($P < 0.05$). @ Significantly greater than women's singles ($P < 0.001$).

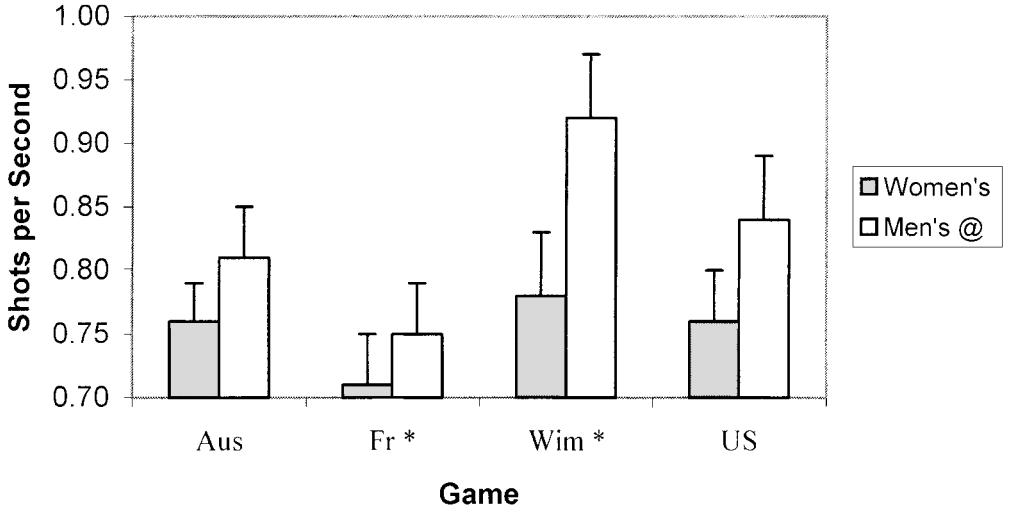

Fig. 2. Shots played per second of rally time. * Significantly different to all other tournaments ($P < 0.05$). @ Significantly lower than women's singles ($P < 0.001$).

Table 5. Timing factors (mean ± *s*)

Timing factor	Sex	Tournament			
		Australian	French	Wimbledon*	US Open
Inter-serve (s)	Women	9.8 ± 0.9	10.4 ± 1.4	10.3 ± 0.9	10.6 ± 1.3
	Men	9.3 ± 1.5	9.2 ± 1.3	11.0 ± 1.3	10.0 ± 1.4
Inter-point (s)	Women	17.1 ± 2.0	18.2 ± 1.6	18.1 ± 1.6	18.1 ± 2.0
	Men[@]	18.7 ± 1.9	19.5 ± 2.1	19.4 ± 1.6	18.3 ± 2.0

* Inter-serve time significantly longer than at the Australian and French Opens ($P < 0.05$). [@] Inter-point time significantly longer than in women's singles ($P < 0.01$).

$P < 0.001$) and court surface ($\chi^2_3 = 64.3$, $P < 0.001$) also had a significant influence on the shot rate.

Table 5 presents the results for other timing factors. The sex of the player did not have a significant influence on inter-serve time ($z = 1.9$, $P > 0.05$); however, the surface of the court did have a significant influence ($\chi^2_3 = 20.4$, $P < 0.001$). Men took a significantly longer interval between points than women ($z = 3.2$, $P < 0.01$), but court surface had no significant influence on inter-point time ($\chi^2_3 = 7.4$, $P > 0.05$).

Types of point

The seven types of point were further categorized into two broad point classes: 'service points' and 'non-service points'. 'Service points' are points that are won or lost on serve or serve return. Points involving three or more shots were classified as 'non-service points'. Figure 3 shows the proportion of 'service points' at each of the tournaments. There were significant differences between the tournaments for the percentages of aces ($\chi^2_3 = 9.9$, $P < 0.05$), double faults ($\chi^2_3 = 13.1$, $P < 0.01$), serve winners ($\chi^2_3 = 35.5$, $P < 0.001$) and serve return winners ($\chi^2_3 = 23.8$, $P < 0.001$). Men played significantly more aces ($z = 8.7$, $P < 0.001$) and serve winners ($z = 7.6$, $P < 0.001$) than women.

Figure 4 shows the proportion of 'non-service points' at each of the tournaments. There were significant differences between the four tournaments for the percentage of points where the server approached the net first ($\chi^2_3 = 43.2$, $P < 0.001$) and the percentage of baseline rallies ($\chi^2_3 = 49.7$, $P < 0.001$). However, there was no significant difference between the tournaments for the proportion of points where the receiving player

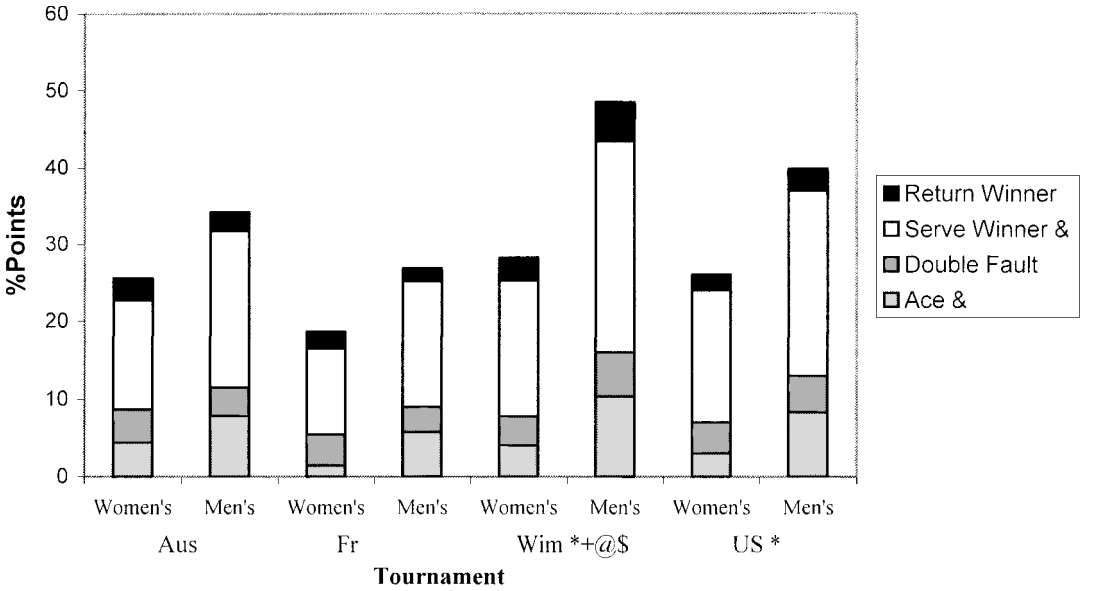

Fig. 3. Proportion of service point types. * Significantly more serve winners than at the French Open ($P < 0.05$). [+] Significantly more serve winners than at the Australian Open ($P < 0.05$). [@] Significantly more aces and double faults than at the French Open ($P < 0.05$). [$] Significantly more return winners than at all other tournaments ($P < 0.05$). [&] Significantly greater in men's singles than women's singles ($P < 0.001$).

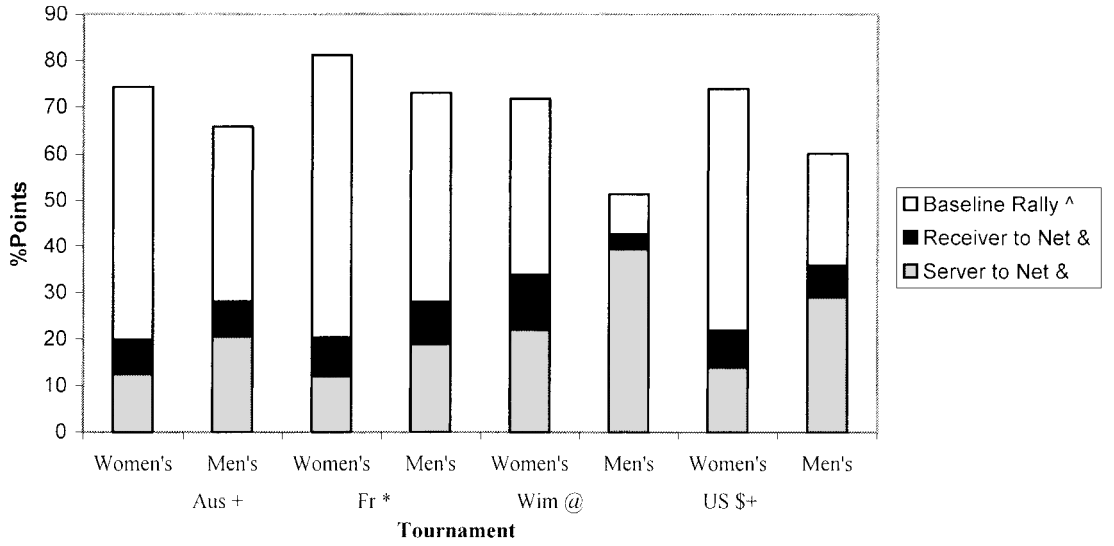

Fig. 4. Proportion of non-service point types. * Significantly more baseline rallies than at all other tournaments ($P < 0.05$). + Significantly more baseline rallies than at Wimbledon ($P < 0.05$). @ Server approached the net significantly more than at all other tournaments ($P < 0.05$). $ Server approached the net significantly more than at the Australian or French Opens ($P < 0.05$). & Significantly greater in men's singles than women's singles ($P < 0.001$). ^ Significantly greater in women's singles than men's singles ($P < 0.001$).

approached the net first ($\chi^2_3 = 6.3$, $P > 0.05$). Men approached the net significantly more often than women when serving ($z = 7.2$, $P < 0.001$) and when receiving ($z = 3.0$, $P < 0.01$), whereas women played significantly more baseline rallies than men ($z = 8.0$, $P < 0.001$).

Effectiveness at the net and baseline

Table 6 shows the percentage of points won when players approached the net. There was no significant difference between the four tournaments in the percentage of points won at the net by the serving player ($\chi^2_3 = 1.8$, $P > 0.05$) or the receiving player ($\chi^2_3 = 1.2$, $P > 0.05$). Women won significantly more points at the net when serving than men ($z = 4.3$, $P < 0.001$), but there was no significant difference between the sexes for the percentage of points won at the net when receiving ($z = 0.6$, $P > 0.05$).

Table 7 shows the percentage of points won when players remained at the baseline. There was no significant difference between the four tournaments in the percentage of points won from the baseline by the serving player ($\chi^2_3 = 16.7$, $P > 0.05$) or the receiving player ($\chi^2_3 = 6.8$, $P > 0.05$). Furthermore, the sex of the player had no significant influence on the percentage of points won when players remained at the baseline when serving ($z = 0.7$, $P > 0.05$) or receiving ($z = 0.7$, $P > 0.05$).

Discussion

The effect of court surface

The court surfaces used at the four Grand Slam tournaments can be classified according to their coefficient

Table 6. Percentage of points won at the net when serving and receiving (mean ± *s*)

		Tournament			
Player	Sex	Australian	French	Wimbledon	US Open
Server	Women*	64.6 ± 12.2	67.8 ± 9.9	65.6 ± 7.6	64.4 ± 12.0
	Men	60.6 ± 8.5	64.5 ± 8.5	58.1 ± 6.0	61.4 ± 7.9
Receiver	Women	68.0 ± 14.5	68.4 ± 13.9	71.8 ± 12.1	67.2 ± 14.2
	Men	59.9 ± 9.8	63.5 ± 10.5	58.3 ± 6.3	61.8 ± 9.3

* Server at net significantly more than in men's singles ($P < 0.01$).

Table 7. Percentage of points won from the baseline when serving and receiving (mean ± *s*)

		Tournament			
Player	Sex	Australian	French	Wimbledon	US Open
Server	Women	46.9 ± 5.8	48.6 ± 5.6	45.7 ± 8.6	47.8 ± 7.1
	Men	48.1 ± 9.7	52.0 ± 8.5	46.6 ± 24.4	47.0 ± 12.2
Receiver	Women	53.1 ± 5.8	51.4 ± 5.6	54.3 ± 8.6	52.2 ± 7.1
	Men	51.9 ± 9.7	48.0 ± 8.5	53.4 ± 24.4	53.0 ± 12.2

of friction and coefficient of restitution. Both of these properties influence the interaction between the tennis ball and the surface of the court (Brody, 1987). The coefficient of friction affects the horizontal component of a tennis ball's velocity. A surface with a low coefficient of friction will cause the ball to bounce faster than a surface with a high coefficient of friction. The coefficient of restitution is the ratio of the vertical component of the tennis ball's velocity after it strikes the surface to that before it strikes the surface. Therefore, a surface with a high coefficient of restitution will cause the tennis ball to bounce higher than a surface with a low coefficient of restitution. Cement and grass courts are very fast, whereas clay and synthetic surfaces can be extremely slow. The current study has shown that rallies at the French Open are significantly longer than those at the Australian and US Opens, which are significantly longer than those at Wimbledon. Furthermore, there was a significantly higher shot rate at Wimbledon than at any other tournament and a significantly lower shot rate at the French Open than at any other tournament. This suggests a relationship between the ball–court interaction, shot rate and the length of rallies. Clay has a higher coefficient of friction and higher coefficient of restitution than the other surfaces, resulting in a high and relatively gentle bounce. This leads to a lower shot rate on clay, which provides the player with more time to play a shot than on faster surfaces. This leads to less difficulty when playing shots, resulting in longer rallies with more shots being played before a winner or an error occurs. The longer rallies that occur on clay result in prolonged matches that induce fatigue, increasing error rates and reducing stroke velocity (Vergauwen *et al.*, 1998). Therefore, players hoping to progress to the latter stages of the French Open should develop good aerobic fitness to delay the onset of fatigue. The present results are in line with those of previous research showing that rallies are significantly longer at the French Open than at Wimbledon in both men's and women's singles (O'Donoghue and Liddle, 1998a). However, our results contradict the finding of Richers (1995) that rallies in elite tennis are of a similar length on clay courts (7.6 ± 6.7 s) and hard courts (8.0 ± 7.4 s). Variability in the length of rallies recorded on each surface by Richers was much higher than for either males or females in the current study.

The inter-serve time observed at Wimbledon was significantly longer than that observed at the Australian and French Opens. This suggests the serve–volley strategy is used to a greater extent at Wimbledon with players 'attacking' the net after a first serve, resulting in a longer walk back to the baseline if a second serve is necessary (Hughes and Clarke, 1995). The longest inter-point times for both men's and women's singles were recorded at the French Open. However, the results suggest that this was not due to players having to walk back to the baseline from the net, as fewer net points were played at the French Open than at any other tournament. An alternative explanation for the longer inter-point times observed at the French Open is that the lower shot rate leads to longer rallies from which players take a longer recovery.

There were significantly more aces played at Wimbledon than at the French Open and significantly more serve winners played at Wimbledon than at the Australian and French Opens. This contradicts the finding of Hughes and Clarke (1995) of no significant difference in the number of serve winners played at the Australian Open and Wimbledon. Significantly more serve winners were also played at the US Open than at the French Open. The slower and higher bounce that occurs at the French Open provides the receiver with more of an opportunity to return the service than on faster surfaces.

In comparing the strategy of male and female tennis players on four different surfaces, eight singles games were analysed, classified by the sex of the player and the surface of the court. We found a decreasing proportion of 'service points' from fast to slow surfaces. If the rally is not won or lost on serve or serve return, each player must decide whether to approach the net. In all eight games, whether serving or receiving, players were more effective at the net than at the baseline. Furthermore, there was no significant difference between the

tournaments in the effectiveness with which players played at the net or from the baseline. Despite the similar effectiveness at the net for the eight games, players approached the net significantly more at Wimbledon and the US Open than at the French and Australian Opens. This may be because of the difficulty playing approach shots on slower surfaces. An approach shot should not only give the player time to approach the net, but should also pressurize the opponent to reduce the risk of a successful passing shot or lob being played. Slower courts may render approach shots less effective than on faster courts and, therefore, players are more reluctant to approach the net at the Australian and French Opens than at Wimbledon and the US Open. Indeed, a strategy of drawing the opponent to the net with shots that are played short has been observed in women's singles at the French Open (O'Donoghue and Liddle, 1998b).

The effect of the sex of the player

The view of Davies (1962) that men's and women's singles would become similar has not yet been realized in Grand Slam tennis based on the results of the present study. Rallies in women's singles were significantly longer than those in men's singles, in line with previous research that found rallies to be significantly longer in women's singles than men's singles at the French Open and Wimbledon (O'Donoghue and Liddle, 1998a). The difference in the lengths of rallies, together with a greater proportion of baseline rallies in women's singles than men's singles, may be explained by greater probing for weaknesses and gradual building of points in women's singles (Gunter, 1973).

Men played significantly more shots per second than women. The greater shot rate in men's singles can in part be explained by the greater proportion of points where players approach the net. This reduces the distance that the ball travels between players in men's singles and thus reduces the inter-shot time. However, the significantly shorter rallies in men's singles suggests that the higher shot rate in men's singles is due to men hitting the ball harder, resulting in shorter rallies before the point ends through a winner or an error being played. The shot rates can be combined with rally times to determine the number of shots per rally for the purpose of comparison with the results of other studies. The number of shots played by men per rally at Wimbledon was 3.13, similar to the figures of 3.09 and 2.97 computed by Hughes and Clarke (1995) and Hughes and Moore (1998) respectively. We also found that there were 4.58 shots per rally in men's singles at the Australian Open, similar to the 4.78 shots per rally reported by Hughes and Clarke (1995).

Men played significantly more aces, serve winners and observably more double faults than women. A mathematical model was developed by George (1973) to determine optimal serving strategies. This model assumed that players have two service types in their arsenal – a strong serve and a weak serve. The strong serve was not only assumed to have a higher probability of being faulted than the weak serve, but also a higher probability of leading to the server winning the point if non-faulted. This model showed that a 'weak–weak' strategy (that is, using the weak service on both first and second serve) would never be optimal. A study of the effectiveness of different service strategies showed that the 'strong–weak' service strategy is not always the best strategy to adopt in the women's game (King and Baker, 1979). The higher proportions of aces, serve winners and double faults in men's singles reported in the current study suggest that the 'strong–strong' strategy may be used as an alternative to the 'strong–weak' strategy to a much greater extent in men's than in women's singles. There were also more serve return winners in men's singles than women's singles, particularly at Wimbledon and the US Open. Where male players adopt a serve–volley strategy at these tournaments, they risk being passed by the return of serve as they approach the net. By approaching the net, serves have less time to reach a good service return than if they had remained at the baseline. Research into soccer has shown that the extent to which players can change direction while moving decreases as the speed of movement increases (Grehaigne *et al.*, 1997). This suggests that when players approach the net quickly, their ability to change direction to reach a return of service played close to the sideline of the court is reduced.

There is some evidence that the women's game involves more strategy than men's singles (Gunter, 1973) with longer rallies and a higher proportion of 'non-service points'. Women played more effectively at the net than men, significantly so when serving. Together with the finding that men approach the net more than women, this suggests that women approach the net after carefully building the point to maximize their chances of winning the point at the net (Davies, 1962). Alternatively, men may approach the net more often, winning less net points than women but still winning over 50% of net points and winning more points at the net than if remaining at the baseline. The lower proportion of net points won by men may also result from the greater shot rate in the men's game increasing the difficulty of volleying and leading to more errors played at the net in men's than in women's singles. All elite players should practise volleying, as attacking the net was a more effective strategy than staying at the baseline when serving and receiving in all eight games.

Conclusions

Eight singles games in Grand Slam tennis were classified by the sex of the players and the surface of the courts. We have highlighted differences between the games in terms of timing factors, shot rates and point profiles. The longest rallies in Grand Slam tennis occurred in women's singles at the French Open, with over 60% of rallies being played from the baseline. Elite women approached the net more at Wimbledon than at any other tournament. The greater shot rate promoted by the fast grass surface may encourage elite players to approach the net, where they can expect to win a greater proportion of points than if they stay at the baseline. Women's singles was very similar at the Australian and US Opens. Elite women remained at the baseline more often at these two tournaments than at Wimbledon.

Elite male players also showed more of a preference for a baseline strategy at the French Open than at the other Grand Slam tournaments. The serve was least dominant at the French Open and male players could not rely on aces and serve winners to provide points as they did at other tournaments. The shortest rallies and highest shot rates in Grand Slam tennis occurred in the men's singles at Wimbledon, where almost half of the points were 'service points'. Unlike women's singles, there were differences between the Australian and US Opens for men's singles. The serve was more important at the US Open, with more serve winners but similar numbers of aces. There were noticeably less baseline rallies at the US Open, with players preferring to approach the net more when serving than at the Australian Open.

The present findings suggest that both the sex of the player and the surface of the court have an effect on the strategy adopted by players at Grand Slam tournaments. Therefore, elite players should not only devise a match strategy based on their own strengths and weaknesses, but the strategy should also be specific to their sex and the court surface to be played on.

References

Altman, D.G. (1991). *Practical Statistics for Medical Research*. London: Chapman & Hall.

Atkinson, G. and Nevill, A.M. (1998). Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Medicine*, **26**, 217–238.

Bland, J.M. and Altman, D.G. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*, **i**, 307–310.

Brody, H. (1987). *Tennis Science for Tennis Players*. Philadelphia, PA: University of Pennsylvania Press.

Davies, M. (1962). *Lawn Tennis*. London: Museum Press.

George, S.L. (1973). Optimal strategy in tennis. *Journal of the Royal Statistical Society Series C*, **22**, 97–104.

Grehaigne, J.F., Bouthier, D. and David, B. (1997). A method to analyse attacking moves in soccer. In *Science and Football III* (edited by T. Reilly, J. Bangsbo and M. Hughes), pp. 258–264. London: E & FN Spon.

Gunter, N.R. (1973). Introduction. In *Tennis for Women* (edited by F. Hovis), pp. 11–12. London: Angus & Robertson.

Hughes, M. and Clarke, S. (1995). Surface effect on elite tennis strategy. In *Science and Racket Sports* (edited by T. Reilly, M. Hughes and A. Lees), pp. 272–277. London: E & FN Spon.

Hughes, M. and Moore, P. (1998). Movement analysis of elite level male 'serve and volley' tennis players. In *Science and Racket Sports II* (edited by A. Lees, I. Maynard, M. Hughes and T. Reilly), pp. 254–259. London: E & FN Spon.

King, H.A. and Baker, J.A.W. (1979). Statistical analysis of service and match play strategies in tennis. *Canadian Journal of Applied Sports Science*, **4**, 298–301.

O'Donoghue, P.G. and Liddle, S.D. (1998a). A notational analysis of time factors of elite men's and ladies' singles tennis on clay and grass surfaces. In *Science and Racket Sports II* (edited by A. Lees, I. Maynard, M. Hughes and T. Reilly), pp. 241–246. London: E & FN Spon.

O'Donoghue, P.G. and Liddle, S.D. (1998b). A match analysis of elite tennis strategy for ladies' singles on clay and grass surfaces. In *Science and Racket Sports II* (edited by A. Lees, I. Maynard, M. Hughes and T. Reilly), pp. 247–253. London: E & FN Spon.

Richers, T.A. (1995). Time–motion analysis of the energy systems in elite and competitive singles tennis. *Journal of Human Movement Studies*, **28**, 73–86.

Underwood, G. and McHeath, J. (1977). Video analysis in tennis coaching. *British Journal of Physical Education*, **8**, 136–138.

Vergauwen, L., Spaepen, A.J., Lefevre, J. and Hespel, P. (1998). Evaluation of stroke performance in tennis. *Medicine and Science in Sports and Exercise*, **30**, 1281–1288.