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ORIGINAL ARTICLE

Performance demands of professional male tennis players

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Objective: To quantify the performance demands in professional male tennis.
Methods: Games from three grand slam tournaments were analysed by an elite tennis player from video recordings. Game related data were collected on 22 players (French Open, 8 (186 games); Wimbledon, 11 (206 games); US Open, 9 (224 games)). Total number of strokes per game was quantified separately for service and return games. Strokes were categorised by type and designated as forehand or backhand. Differences in the types of strokes in a game were analysed using one factor (type of stroke) repeated measures analysis of variance. Differences in total strokes and stroke distributions between playing surfaces were analysed by analysis of variance (surface type) with Tukey's post hoc pairwise comparisons.
Results: For service games there were more serves per game than any other type of stroke ($p<0.001$), with topspin forehand and topspin backhand the only other strokes averaging more than one per service game. For return games there were more forehand and backhand returns and topspin forehands and backhands than other types of stroke ($p<0.01$). Total number of strokes per game was greater in the French Open than Wimbledon ($p<0.01$), with more topspin forehands ($p<0.01$) and more topspin backhands ($p<0.01$). Total strokes per game in the US Open were not different from the other two tournaments.
Conclusions: The serve was the predominant stroke accounting for 45% (French Open) to 60% (Wimbledon) of strokes during service games. The greater number of strokes per game on clay *v* grass may contribute to earlier fatigue.

Professional tennis is a year round sport with a different tournament or competition every week. Most injuries in this population of athletes involve the shoulder and are secondary to overuse.[1–3] It has been reported that over 50% of world class players experience shoulder symptoms during their career and 80% of theses cases stem from overuse.[3 4] The areas of the shoulder most commonly affected include one or more of the following: the rotator cuff, biceps tendon, scapular region, glenohumeral ligaments, and the glenoid labrum.[5] As the overhand racquet motion subjects the shoulder girdle complex to similar stresses as those seen in throwing, injury patterns and glenohumeral internal rotation deficits among elite tennis players are similar to those of professional baseball pitchers.[6 7] In contrast to baseball, where various pitch statistics are maintained for all pitchers, no such statistics are maintained for tennis players. Additionally the effect of different tennis playing surfaces on the number of strokes and stroke selection is not known. Our aim in this study was therefore to determine the performance demands of professional male tennis by documenting the number and type of strokes during professional tennis matches on different surfaces. While several papers have been written about tennis related injuries,[1–13] this is the first one to our knowledge that has attempted to quantify the performance demands of the sport among world class players.

METHODS

Games from three grand slam tournaments during the 2003 season were analysed (French Open, Wimbledon, and US Open) by an elite tennis player from video recordings. These tournaments were selected on the basis of the differences in playing surface (French Open, clay; Wimbledon, grass; US Open, hard). Game related data were collected on a 22 different male players (eight in the French Open, 11 at Wimbledon, and nine in the US Open) with three players analysed in all three tournaments and three players analysed in two of the three tournaments. Games were analysed separately for service and return games. The total number of games analysed for each tournament was 186 for the French Open, 206 for Wimbledon, and 224 for the US Open. An equal number of service and return games was analysed for each tournament. The total number of strokes per game was quantified separately for service and return games. Strokes were categorised as serves (first and second), topspin, slice, half volley, volley, return (return games only), and overhead, and designated as forehand or backhand as appropriate. As ball velocity is markedly higher for serves than for other strokes, service returns were not grouped with other ground strokes and were categorised as a forehand or backhand return regardless of the spin placed on the ball (for example, topspin or slice). Backhand overheads were categorised as backhand volleys because the ball velocity is significantly less in backhand overheads than in forehand overheads.

Differences in the type of strokes executed within a game were analysed using one factor (type of stroke) repeated measures analysis of variance with Bonferroni corrections for post hoc pairwise comparisons. Differences in total strokes and stroke distributions between playing surfaces were analysed using analysis of variance (surface type) with Tukey's post hoc pairwise comparisons. Results are reported as mean (SD). Total strokes and strokes per game are reported separately for servers and returners.

RESULTS

For service games (table 1) there were more serves per game (mean (SD), 8.9 (4.7)) than any other type of stroke ($p<0.01$), with topspin forehand (4.4 (4.2)) and topspin backhand (3.0 (3.6)) being the only other strokes that averaged more than one per service game.

For return games (table 2) there were more forehand and backhand returns (2.3 (1.7) and 3.0 (1.9)) and topspin forehands and backhands (3.0 (3.4) and 2.6 (3.1)) than other types of stroke ($p<0.01$).

Combined data from all three tournaments on the number of strokes and stroke distribution are given in table 3. The

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Table 1 Data on the number of strokes and stroke distribution for service games in the three tournaments: service games

Stroke type		US Open	French Open	Wimbledon
Total strokes		17.9 (12.1)	21.0 (10.2)	16.0 (8.9)
Serves	First	6.4 (3.2)	6.5 (2.3)	6.4 (2.9)
	Second	2.5 (2.1)	2.4 (1.7)	2.6 (2.0)
Top spin	Fore	4.3 (4.3)	6.0 (4.2)	2.9 (3.4)
	Back	3.4 (3.8)	4.2 (4.0)	1.3 (1.9)
Slice	Fore	0.1 (0.3)	0.4 (1.3)	0.1 (0.3)
	Back	0.5 (1.0)	0.7 (1.1)	0.3 (0.7)
Half volley	Fore	0.1 (0.2)	0.1 (0.5)	0.3 (0.6)
	Back	0.1 (0.3)	0.03 (0.2)	0.2 (0.5)
Volley	Fore	0.2 (0.4)	0.2 (0.4)	0.6 (0.9)
	Back	0.3 (0.7)	0.1 (0.4)	0.9 (1.5)
Overhead		0.1 (0.4)	0.2 (0.6)	0.2 (0.6)

See results section for statistical analysis. Values are mean (SD).

total number of strokes per game was higher in the French Open than in Wimbledon (service game: 21.0 (10.2) *v* 16.0 (8.9), $p<0.01$; return game: 14.8 (9.2) *v* 10.4 (6.0), $p<0.01$). The difference in total strokes was primarily accounted for by more topspin forehands (service games: 6.0 (4.2) *v* 2.9 (3.4), $p<0.01$; return games: 3.2 (3.8) *v* 2.0 (2.2), $p<0.01$) and more topspin backhands (service game: 4.2 (4.0) *v* 1.3 (1.9), $p<0.01$; return game: 3.7 (3.7) *v* 1.8 (1.8), $p<0.01$). Total strokes per game in the US Open (service game: 17.9 (12.1), return game 12.2 (10.0)) did not differ significantly from the other two tournaments.

There were more forehand and backhand volleys ($p<0.01$) for service games in Wimbledon (forehand: 0.6 (0.9); backhand: 0.9 (1.5)) than in French Open (forehand: 0.2 (0.4); backhand: 0.1 (0.4)) or the US Open (forehand: 0.2 (0.4); backhand: 0.3 (0.7)).

Serves (first and second) accounted for 45 (12)% of total strokes during service games in the French Open, which was less than for both Wimbledon (60 (17)%, $p<0.01$) and the US Open (56 (18)%, $p<0.01$). Topspin forehands accounted for 28 (11)% of service points in the French Open, which was more than for the US Open (21 (12)%, $p<0.01$) or Wimbledon (16 (14)%). Additionally, topspin backhands accounted for 18 (12)% of service points in the French Open which was more than for Wimbledon (7 (8)%, $p<0.01$). Similarly, for return games there was a higher proportion of topspin forehands and topspin backhands in the French Open (24 (12)% and 21 (15)%, respectively) than at Wimbledon (16 (13)% and 16 (14)%, respectively; all $p<0.05$)

DISCUSSION

Stroke production in tennis involves generating repetitive forces and motions that are of high intensity and short duration. These forces consistently subject the shoulder region to high stress over the course of games, practice sessions, and match play.[14] This is particularly evident in the case of the serve, which has been documented to be the most strenuous stroke on the upper extremity.[15] Over half of the total force developed during the serve is generated from the lower extremity and trunk musculature.[14] The shoulder plays a crucial role in the kinetic chain to transfer these forces to the hand and racquet. This leads to high levels of muscle activity not only to enhance the bony and ligamentous systems of the shoulder region but also to produce motion, which is accomplished by an explosive contraction of the internal rotators with the shoulder in an abducted position. Fleisig *et al*[16] documented internal rotation velocities of the humerus among elite players to reach 2420°/s during the acceleration phase of the serve. Similar to professional baseball pitchers, range of motion demands on the dominant shoulder are also extremely high. Dillman reported maximal shoulder external rotation values of 154° during the serve (Dillman CJ, unpublished data presented at the United States Tennis Association National Meeting, Tucson, Arizona, 1991). Competitive baseball pitchers and tennis players also show shoulder internal rotation range of motion deficits on the dominant shoulder. This is most probably the result of repetitive microtrauma during the deceleration phase of the pitching and service motion which leads to scar formation and subsequent posterior capsule contracture.[6] Considering

Table 2 Data on the number of strokes and stroke distribution for return games in the three tournaments: return games

Stroke type		US Open	French Open	Wimbledon
Total strokes		12.2 (10.0)	14.8 (9.2)	10.4 (6.0)
Returns	Fore	2.0 (1.5)	2.8 (1.9)	2.3 (1.5)
	Back	3.2 (2.3)	3.0 (1.7)	2.9 (1.6)
Topspin	Fore	3.2 (3.8)	3.2 (3.8)	2.0 (2.2)
	Back	2.5 (3.5)	3.7 (3.7)	1.8 (1.8)
Slice	Fore	0.2 (0.5)	0.4 (1.1)	0.1 (0.4)
	Back	0.9 (1.4)	0.7 (0.9)	0.8 (1.2)
Half volley	Fore	0.03 (0.2)	0.06 (0.2)	0.1 (0.3)
	Back	0.05 (0.3)	0.02 (0.2)	0.08 (0.3)
Volley	Fore	0.04 (0.2)	0.09 (0.3)	0.09 (0.3)
	Back	0.09 (0.3)	0.07 (0.3)	0.1 (0.5)
Overhead		0.0 (0.0)	0.03 (0.2)	0.04 (0.2)

See results section for statistical analysis. Values are mean (SD).

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Table 3 Combined data from all three tournaments on the number of strokes and stroke distribution (see results section for statistical analysis). Service and return games

Service games			Return games		
Stroke type			**Stroke type**		
Serves	First	6.4 (2.9)	Returns	Fore	2.3 (1.7)
	Second	2.5 (1.9)		Back	3.0 (1.9)
Topspin	Fore	4.4 (4.2)	Topspin	Fore	3.0 (3.4)
	Back	3.0 (3.6)		Back	2.6 (3.1)
Slice	Fore	0.2 (0.8)	Slice	Fore	0.2 (0.7)
	Back	0.5 (1.0)		Back	0.8 (1.2)
Half volley	Fore	0.2 (0.5)	Half volley	Fore	0.1 (0.3)
	Back	0.1 (0.4)		Back	0.1 (0.2)
Volley	Fore	0.3 (0.7)	Volley	Fore	0.1 (0.3)
	Back	0.4 (1.0)		Back	0.1 (0.4)
Overhead		0.2 (0.5)	Overhead		0.02 (0.2)

See results section for statistical analysis. Values are mean (SD).

the high joint velocities, extreme external range of motion during the serve, and internal rotation deficits coupled with the fact that serves account for approximately 45% (French Open) to 60% (Wimbledon) of the total strokes during service games, it is not surprising that shoulder injuries are so prevalent in elite tennis players.

The winner of the 2003 US Open averaged 7.8 (3.2) serves per game for 31 service games analysed. Over the two week period of the tournament he had seven matches including approximately 120 service games. Therefore it is estimated that he hit over 1000 serves in singles match play alone when factoring in serves in tiebreakers (he played seven tiebreakers in the tournament). By contrast, an elite professional baseball pitcher typically pitches every four days with an average of approximately 100 pitches per game. For example, during the 2004 Major League Baseball (MLB) playoffs, a prominent pitcher threw in four games over a 16 day period. During this time, he averaged 102.8 (16.5) pitches and 6.3 (1.0) innings pitched per game. The total number of pitches was 411, which is markedly less than the total number of serves a professional tennis player hits in a similar time period. Given the combination of high demand and limited rest for tennis players, it is understandable that impingement of the rotator cuff and biceps tendon, anterior capsule attenuation, or intrinsic tendon overload of the posterior shoulder musculature, or combinations of these, occur frequently.

In addition to the serve, ground strokes place additional stress on the shoulder, though to a lesser degree. Our results showed that for service games topspin ground strokes were the second most frequently hit strokes, while for return games there were more topspin ground strokes and service returns than all other strokes. While muscle activity during the preparation phase of ground strokes is minimal, the acceleration and follow-through phases yield much higher activity.[17] Electromyography during the forehand yields high activity in the subscapularis, biceps brachii, pectoralis major, and serratus anterior. The serratus anterior, subscapularis, infraspinatus, and biceps are also moderately active during the follow through. With regard to the backhand, the middle deltoid, supraspinatus, and infraspinatus show a high degree of activity during acceleration. These muscles are also active during the follow through, along with the biceps, though to a lesser degree. While service returns are also frequently hit strokes, the forces placed on the shoulder are not known; it is likely that they would be similar to those of ground strokes during the acceleration phase. While the other stroke types documented do occur during match play, they are less prevalent and most probably do not play a major role in contributing to injuries sustained by elite tennis players.

The impact of tennis court surface was evident when comparing the total number of strokes across tournaments. The fact that total number of strokes per game was greater in the French Open than at Wimbledon is consistent with clay being a slower court surface than grass. The difference in total strokes was primarily accounted for by a larger number of topspin ground strokes and is consistent with longer rallies. The greater number of strokes on clay may contribute to earlier fatigue and possibly to a higher prevalence of injury, especially if players are forced to compete on consecutive days.

This study was based on data from grand slam events, which require players to win three of five sets. It should be mentioned that this format does not exist for every tournament. The other format used on the ATP Tour requires the player to win two of three sets, and tournaments are typically structured so that players compete on a daily basis for approximately seven to 10 days. With this schedule, players essentially compete in a different tournament every week with minimal or no rest. Thus it seems that it may be as demanding as competing in a grand slam event.

The present study is the first attempt to our knowledge to quantify the performance demands of tennis among elite players. This information is valuable for several reasons. First,

What is known on this topic

- Professional tennis is a year round sport with a different tournament or competition every week. Most injuries involve the shoulder and are secondary to overuse
- Several papers have been written about tennis related injuries, stroke biomechanics, racquet characteristics, injury prevention, and rehabilitation and conditioning programmes, but none has attempted to quantify the performance demands of the sport among elite tennis players

What this study adds

- This study provides objective information that may improving training techniques, coaching tactics, and clinical decision making
- It can serve as a template to be applied to other populations of competitive tennis players, especially at the junior level, in an effort to safeguard against injury

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it may provide the necessary information to develop data based rehabilitation programmes that can safely return elite male tennis players to competition. While tennis rehabilitation programmes do exist[1 18] they are not based on objective data but rather on an expert's knowledge of the sport and are modified according to a player's skill level. Second, as serves, service returns, and topspin ground strokes are the predominant strokes, coaches should emphasise proper mechanics and training of these stroke types. Finally, this study may serve as a template that can be applied to competitive junior players. By determining the performance demands of the sport in this population, we will gain valuable data that may justify the need to modify tournament structure and training routines to safeguard against injury.

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COMMENTARY 1

The authors have made a valid point that current rehabilitation programmes[1] are based mainly on expert knowledge of the sport rather than on objective data. This study provides the first in-depth breakdown and analysis of the type of strokes played in actual matches. The results, however, are not particularly surprising and confirm what could have been predicted pre-study: serves are the dominant stroke and probably contribute most to the high prevalence of shoulder injuries in tennis.[2] Nevertheless this study should serve to assist others explore the specific demands of the game and how they contribute to injury.

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COMMENTARY 2

This paper presents further information regarding the sport specific intrinsic demands that are placed on athletes. This helps us to understand the nature and distribution of injuries in a sport, allows some guidance for clinicians in developing injury prevention strategies, and also helps coaches develop programmes to improve performance in the different strokes. Some of the findings are intuitive. It is not surprising that more strokes are hit when playing on a slower surface, and that serves comprise a smaller percentage on those slower surfaces. However, the data do emphasise the importance and the predominance of the service motion in professional play, and point to the need for interventions to increase the player's capability of withstanding these demands, which should maintain performance with minimal injury risk.

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