Performance analysis research has been carried out on the four main racket sports: tennis, squash, badminton and table tennis. This chapter surveys the research that has been completed since the last main reviews of science and racket sports by Hughes (1998), Lees (2003) and O’Donoghue (2004). Analysis of shot technique has been carried out using kinetic and kinematic analyses, with methods following advances in technology. Technical effectiveness is a broader analysis of tennis performance, assessing winner-to-error ratios and percentages of different point types that are won. Point sequences have been used to investigate momentum, stationarity and independence of points. Tactical analysis has been applied in racket sports using modern eye-tracking systems, as well as more broadly by examining point profiles. The physical demands of racket sports can be estimated using observational techniques, rally and rest timings, heart-rate responses, blood lactate concentration and perceived exertion.

Introduction

There are four main racket sports (tennis, badminton, squash and table tennis), with some other racket sports being played to a lesser extent. Racket sports can be played with a net dividing the players or, in the case of squash, with the players moving in a common court area. The common aspects of racket sports are that shots are played by competitors in alternation, forming rallies. There are singles and doubles games in all four main racket sports. The purpose of this chapter is to review performance analysis research in racket sports. There have been previous reviews of notational analysis and performance analysis in racket sports (Hughes, 1998; O’Donoghue, 2004) and a review of science and racket sports that includes performance analysis research (Lees, 2003). The current chapter covers recent contributions that have been made since these reviews were completed.

The review is structured into four parts to deal with four of the purposes of performance analysis that are relevant to the study of racket sports. Technique analysis is concerned with mechanical aspects of technique and how skills are performed. Technical effectiveness, on the other hand, is concerned with outcomes of skills performed, irrespective of how correctly a skill
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has been performed. Tactical analysis is concerned with strategies and tactical decisions that are manifested in observable patterns of play. Finally, physical aspects of performance can be investigated through analysis of rally lengths and estimates of game intensity. Direction for future research efforts in performance analysis of racket sports is given at the end of the chapter.

Technique analysis

Performance analysis typically involves analysis of data gathered during actual sport competitions. However, there are occasions where detailed analysis of technique requires data collection during controlled laboratory experiments. Such research still falls under the umbrella of performance analysis of sport where the techniques being investigated are key aspects of the sport that cannot be studied to the required level of detail during actual competition (O’Donoghue, 2010: 2). This section covers the main research developments in technique in racket sports. The studies reviewed have to manage the balance between the need for experimental control and the need for ecological validity in order to investigate relevant aspects of racket sport skills. There are numerous biomechanical principles, yet those proposed to be most relevant to understanding stroke technique are the stretch–shorten cycle, the use of coordinated segment rotations (kinematic chain principle) and the distance over which racket speed can be developed (Elliott, 2006). Two- and three-dimensional videography, force plate/plantar loading analysis and electromyography have been employed to critique the biomechanics of different strokes.

Kinematic analyses of racket sport skills have generally shown that segment endpoint velocities increase in proximal to distal fashion. This has been demonstrated to characterise the tennis serve and groundstrokes (Reid and Elliott, 2002; Reid et al., 2008), the squash forehand (Elliott et al., 1996) and the table tennis forehand (Iino et al., 2008; Iino and Kojima, 2009), and it is only long axis (or more specifically internal rotation) of the upper arm that has been reported to occur out of sequence (Takahashi et al., 1996). It is intuitive that there are some similarities in the kinematic sequencing that epitomises the stroke production of the different racket sport skills. However, the disparate dimensions of the court as well as differences in equipment (inertia of racket and ball/shuttlecock) presumably contribute to subtle variation in each of the shot’s swing shapes and associated joint coordination. For example, where Iino et al. (2008) and Iino and Kojima (2009) have focused on the role of wrist flexion in the table tennis backhand and forehand, tennis studies have generally attended to whole-body kinematics to inform a coach’s view of how end-point velocity is developed from the ‘ground up’. Kinematic analysis has provided evidence that, while tennis players reproduce broad techniques when returning serve, they also adapt technique to deal with specific serve return situations (Gillet et al., 2010).

Landlinger et al. (2010) used kinematic analysis to show that level of player was a further source of variability in forehand technique in tennis.

Evaluations of the kinetics of stroke or movement production in racket sports have employed force transducers, force platforms and three-dimensional modelling techniques. Researchers have often focused on kinetics, which explain the forces that produce movement, to better understand the relationship between stroke production and injury. The type of serves or hitting stance of groundstrokes are known to produce higher trunk and upper-limb loading conditions (Bahamonde and Knudson, 2003; Reid et al., 2008). The generation of ground reaction force, which helps to account for players’ lower limb drive to the ball and plays an important role in the production of all strokes and movements, has been shown to increase with expertise in specific racket sport skills (Girard et al., 2005). In badminton, Kuntze et al. (2010) investigated the kinematics and ground reaction forces of three common types of lunges: the kick lunge, the step-in lunge and the hop lunge. The results suggested that the step-in lunge may be beneficial.
for reducing the muscular demands of lunge recovery, while the hop lunge allows higher positive power output. Where ground reaction forces provide insights into a player’s lower-limb drive, the use of pressure insoles provides researchers and coaches with more specific data to describe the interaction between the shoe and the surface on which racket sport players compete. By using pressure insoles divided into nine areas, Girard et al. (2007a) reported that hard versus clay courts induced higher loading in the hallux and lesser toe areas but lower relative load on the medial and lateral mid-foot in competitive players during tennis-specific movements. In-shoe loading patterns in each foot (back and front) were also shown to differ between two types of tennis serve (first and second serve) and two service stance styles (foot-up and foot-back techniques) (Girard et al., 2010a). Interestingly, the type of court surface was observed to have a significant effect on plantar pressures characterising the first serve in tennis. Compared to hard courts, a reduced asymmetry in peak and mean pressures between the two feet was found on clay, suggesting a greater need for stability on this surface (Girard et al., 2010b). The differences in loading patterns are important for understanding potential injury mechanisms and designing appropriate preventive strategies.

Information concerning the timing and magnitude of muscular activity during the different phases of a particular movement can be gained from electromyography (EMG) recordings. Recent efforts have been made to include EMG data during tennis strokes, such as the serve (Girard et al., 2005), the forehand (Rogowski et al., 2011) and the volley (Chow et al., 2007), while the research attention afforded to the other racket sports has been less extensive. Indeed, the work of Sakurai and Ohtsuki (2000) represents one of very few studies to have examined the EMG characteristics of a badminton stroke, the smash. In comparing the smash of skilled and unskilled players, they revealed similar proximal upper-limb EMG patterns but with significantly more variability in the distal upper-limb EMG characteristics of the unskilled players. Although trunk (Chow et al., 2003) and lower-limb (Girard et al., 2005) muscular activity levels have been investigated, most of the EMG analyses of tennis strokes have focused on the muscles of the hitting arm and shoulder region (Rogowski et al., 2011; Seeley et al., 2008; Wei et al., 2006). Pre- and post-impact activation of five upper extremity muscles in the tennis volley were compared across conditions of ball speed and ball type in a group of 24 recreational tennis players (Chow et al., 2007). In this study, oversize tennis balls did not significantly increase upper extremity muscle activation compared to regular size balls during a tennis volley. Of further interest was the highest post-impact activation observed in the extensor carpi radialis, which is indicative of vigorous wrist stabilisation that may irritate players with lateral epicondylalgia. To this end, EMG can also inform sports medicine professionals and coaches about the injury potential of different players or techniques.

Technical effectiveness

Technical effectiveness provides an abstract portrayal of the performance of skills within sport using positive-to-negative ratios, percentage of successful executions and, specifically in racket sports, winner-to-error ratios. This type of analysis does not go into mechanical detail of the skills that are applied, but technical effectiveness can be used in a complementary fashion with technique analysis, as described by Bartlett’s (2001) unified approach. The simplest type of technical effectiveness examines point outcomes. For example, Gale (1971) proposed the model shown in equation (32.1) for the probability of winning a point. In this equation, \( p_1 \) and \( p_2 \) are the probabilities of the first and second serves being played in, respectively, while \( q_1 \) and \( q_2 \) are the conditional probabilities of the point being won by the server given that the first or second serve is in, respectively.
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\[ P = p_1.q_1 + (1 - p_1).p_2.q_2 \]  
(32.1)

O’Donoghue (2009a) applied this equation to published statistics for 427 completed women’s singles matches in the 2007 and 2008 Australian and US Open tournaments. This analysis showed that 242 of the 854 serving performances would have won more points if the second serve was played like the first serve, 265 would have been more effective if the first serve was played like the second serve and two performances would have been more effective if the first serve was played like the second serve and vice versa. This left a minority of 345 of 854 serving performances where the observed strategy was the most effective for winning points on serve.

Models for the probability of winning service games in tennis have been used to investigate different scoring systems (Croucher, 1982, 1998). These models are based on the assumptions of stationarity and independence of points. Stationarity means that the probability of winning a point is the same irrespective of the score within the game. Independence means that the probability of winning a point is the same no matter what happened in the preceding points. Recently, Knight and O’Donoghue (in press) challenged the assumption of stationarity, finding that players were significantly more likely to win break points than non-break points when receiving serve. However, O’Donoghue and Brown (2009) were unable to challenge the assumption of independence of points when they analysed 26 serving performances from 13 men’s singles matches of over 200 points played at Grand Slam tournaments. This research suggests that momentum in tennis is a misperception of players, coaches, spectators and commentators. There has been some speculation about momentum in squash (Davies et al., 2008; Hughes et al., 2006); however, these studies failed to use inferential statistical procedures to demonstrate that there were more longer sequences of winning (or losing) points than would be expected by chance.

In tennis, the effectiveness of net play and baseline play has been analysed using the percentage of points won in Grand Slam singles tennis (O’Donoghue and Ingram, 2001). Stroke effectiveness has been analysed in table tennis (Djokic, 2002), squash (Brown and Hughes, 1995) and badminton (Cabello-Manrique and González-Badillo, 2003; Oswald, 2009) by counting winners, faults and unforced errors. This is very challenging and requires knowledgeable observers to classify errors during data collection. The percentage of unforced errors is a valid performance indicator in all racket sports when the data are reliable. However, at the elite level, some errors may appear to be unforced but observers need to take into consideration the quality of the shot that a player is trying to return. It was for this reason that O’Donoghue and Ingram (2001) decided to classify point outcomes as winners or errors without distinguishing between forced and unforced errors.

**Tactical analysis**

Technique analysis can be thought of as investigating whether a skill is being performed correctly. Tactical analysis, on the other hand, is concerned with whether the correct skill is being performed. Irrespective of the quality of execution of a skill, tactical analysis is concerned with the decision to select the skill rather than the other options that may have been available in the given situation. Performance analysis typically uses observational techniques, which cannot directly observe the strategy decided prior to a match or moment-to-moment tactical decisions that are made within a match. However, patterns of play in sports allow inferences to be made about the strategies and tactics adopted by players. The types of events performed, the location of events and timings of events all give indications of strategic and tactical decisions that are made by players.
In racket sports, tactics can be inferred from player positioning (Underwood and McHeath, 1977), point profiles (O’Donoghue and Liddle, 1998), rally duration (O’Donoghue and Ingram, 2001; Ming et al., 2008), shot types (Oswald, 2009) and shot placement (Hughes and Clarke, 1995). Service strategy is an important aspect of table tennis that has been analysed by examining the use of forehand and backhand serves, direction of serve, application of spin and depth of serve (Drianovski and Otcheva, 2002). Service placement has also been used as an indicator of strategy in tennis, with players showing a tendency to serve to the backhand of both right-handed and left-handed opponents (O’Donoghue, 2009b). Unierzyski and Wieczorek (2004) found that serve placement may also be influenced by court surface, with fast tennis courts favouring serves to the ‘T’, while slower courts favour more serves played to wide areas to open up the court.

The profile of shots played is also an indicator of strategy. This was one of the indicators of strategy that showed similarities in 21 and 15-point (11-point for women) badminton matches (Ming et al., 2008). Another indicator of strategy is the proportion of points of two or more shots where players attack the net (O’Donoghue and Ingram, 2001). The exclusion of aces, double faults, serve winners and return winners means that only those points where players had an option to approach the net were considered.

Player movement is dictated by tactical concerns, with squash players seeking to position themselves around the ‘T’ in between shots to give the optimal chance of reaching whatever shot the opponent plays. Vučković et al. (2009) used the SAGIT/Squash player-tracking system to compare the movement patterns of squash players in a world team championship with players in Slovenian national championships and a local recreational tournament. The system uses image-processing techniques to analyse play filmed by a camera located on the ceiling of the squash court. The clearest finding of this study was that players at higher levels of the game spent more time in the ‘T’ area when the opponents were playing shots than players at lower levels. Furthermore, winning players in Slovenian national championships and the local recreational tournament spent more time at the ‘T’ than losing players at these tournaments. A later paper by Vučković et al. (2010) revealed limited reliability of the SAGIT/Squash system; however, much of the measurement error reported may be systematic error that can be corrected during analysis, rather than random error.

Although much tactical analysis research in racket sports has been done using data from actual competition, there is still scope for controlled experimental investigation in the study of decision making and tactics in racket sports. An example in table tennis used kinematic analysis as well as line of gaze to investigate visual and motor behaviour during forehand strokes (Rodrigues et al., 2002). Mobile eye-tracker technology was used with an image mixer to present the eye image, the player’s view and an observer’s view of forehands played. A serving player fed balls consistently, with pre-, early and late cues indicating the target location that forehands were to be played to. ‘Quiet eye’ was defined as the duration of final fixation on a crucial location before the initiation of action. This study showed that lower-skilled players had a later ‘quiet eye’ onset during missed shots than successful shots, while higher-skilled players had similar ‘quiet eye’ onset between missed shots and successful shots.

Tactical analysis can be limited when using event frequencies and summary data for whole performances. Temporal analysis is concerned with sequences of events and probabilities of options being chosen in different situations. One example of such research in table tennis is the Markov chain model of table tennis strokes developed by Pfeiffer et al. (2010). This model showed states within rallies and the events which resulted in state transitions. The model covered game actions, stroke position, the direction shots were played and detail of the technique used. The temporal information was displayed in the form of transition matrices and state charts.
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Physical aspects of play

The physical demands of racket sports can be investigated using observational methods to evaluate movement characteristics as well as estimates of game intensity, including heart-rate response (HR), measures of oxygen consumption (VO₂), blood lactate concentration ([La]) and rating of perceived exertion (Fernandez Fernandez et al., 2006; Gomes et al., 2011). The average physiological responses to tennis match play have been reported to be rather modest, with mean exercise intensities of 60–70 per cent VO₂max and 60–80 per cent HR max. In general, [La] values do not exceed 4 mmol.l⁻¹. In squash, the mean intensity is higher: 70–85 per cent VO₂max and 80–90 per cent HR max with [La] up to 8–9 mmol.l⁻¹ (Girard et al., 2007b). Game intensity in badminton (75–85 per cent VO₂max; 75–90 per cent HR max; 3 < [La] < 6 mmol.l⁻¹) is generally lower than in squash but higher than in tennis (Faude et al., 2007). To date, the limited data available during table tennis match play in internationally competing juniors have demonstrated low cardiorespiratory and metabolic demands (VO₂ = 26 ml.kg⁻¹.min⁻¹; HR = 126 beat.min⁻¹; [La] = 1.1 mmol.l⁻¹) (Sperlich et al., 2011). Thus the physical and physiological demands in racket sports can vary to a large extent and can be influenced by a multitude of factors, such as the style of the player, the gender, the level and style of the opponent, the surface, the equipment (i.e. missile and racket characteristics) and the environmental factors (i.e. temperature and humidity) (Fernandez Fernandez et al., 2006). In tennis, being female, slower surfaces, type 3 balls, longer match duration and baseline play increase the aerobic demands, whereas being male, fast surfaces, type 1 balls, shorter match duration, serve and volley play increase the anaerobic demands.

The duration of competition in racket sports varies from 30 to 60 minutes in squash and badminton to more than five hours in tennis, but average durations of 30–90 minutes are common in all racket sports. A broad analysis of the demands of racket sports can be done using rally times and inter-rally breaks; this has been done in tennis (O’Donoghue and Ingram, 2001), badminton (Cabello-Manrique and González-Badillo, 2003) and squash (Girard et al., 2007b). In most high-level matches, the rallies last on average between 2 and 20 s and the work-to-rest ratio between 1:1.1 and 1:1.5. Nevertheless, match activity varies widely across racket sports. In Grand Slam tennis, the mean duration of rally and resting periods are approximately 4–8 s and 20 s, respectively (O’Donoghue and Ingram, 2001). Rally times have been found to be longer (9 s) in regional and national level tennis tournaments but resting periods are still about 20 s (Torres-Luque et al., 2011). The average effective playing time ranges usually between 10 per cent and 30 per cent of the game duration, whereas, in squash, the point duration is longer (10–20 s) and the resting period is shorter (7–8 s), so the effective playing time is 50–70 per cent (Girard et al., 2007b; Montpetit, 1990). The mean rally length fails to portray the demands of a game as there can be a full range of rally lengths. For example, in international badminton singles, the mean rally duration has been measured at 6.4 s (Cabello-Manrique and González-Badillo, 2003). However, only 61.7 per cent of rallies were between 3 s and 9 s in duration. Similarly, the mean rest duration in international badminton was measured at 12.9 s but only 48.6 per cent of rests were between 9 s and 15 s (Cabello-Manrique and González-Badillo, 2003).

A tennis player typically runs an average of 3 m per shot and a total of 8–12 m in the course of a point, completing 300–500 high-intensity efforts during a best-of-three set match (Fernandez Fernandez et al., 2009). The number of directional changes in an average point is four. About 80 per cent of all strokes are played within 2.5 m of the player’s ready position, while about 10 per cent of strokes are made with 2.5–4.5 m of movement. Liddle et al. (1996) used notational analysis to estimate that male badminton players cover 18.6 m during a singles rally and 9.5 m during a men’s doubles rally. Distances covered in squash can now be measured using automatic
player-tracking systems such as SAGIT/Squash (Vučković et al., 2010). The reliability of this system has been reported without breaking the error down into systematic bias and random error components. It is therefore difficult to assess whether SAGIT/Squash is sufficiently reliable for different types of study, but further analysis of reliability data should be able to analyse those types of study where the system can be applied.

The activity within rallies is difficult to characterise using the locomotive movement classes typically used in time-motion studies of field games. Therefore, researchers have developed more specific movement classifications to describe the activity within rallies in racket sports. Richers (1995) introduced the concept of continuous footstep movements to study movement within tennis rallies. She found that there were between five and six footsteps taken within average footstep movements during rallies on clay, grass and cement surfaces. However, the 2.5 continuous footstep movements made per rally on grass was lower than the 3.6 movements on clay and the 3.9 movements on cement. Robinson and O’Donoghue (2008) compared path changes, accelerations and decelerations made by Roger Federer and Rafael Nadal on grass and clay courts. This showed that there were more path changes of 45 to 135 degrees to the left on grass than on clay. Clay-court play was characterised by more braking movements and accelerations from a stationary state than grass-court play. This was because a player making a shot on clay was able to move back to the centre of the baseline and pause before having to decide where to move to play the next shot. On a grass court, the players often had to move directly from one side of the baseline to the other without pausing in the middle. Experimental research has shown that performing path changes during movements elevates the oxygen cost of movements (Botton et al., 2011). Performing 50 path changes per minute involved a greater oxygen cost than 33 path changes per minute, which in turn involved a greater oxygen cost than 22 path changes per minute at a range of running speeds. Further, the concept of ‘velocity coupling’ behaviour, which is a perceptual motor behaviour that occurs during coincident timing tasks such as racket sports, has been found to increase oxygen uptake, blood lactate concentration, heart rate, rating of perceived exertion and perceived task difficulty in tennis (Cooke and Davey, 2007).

Fatigue impairs racket sports performance and is manifested by mistimed shots, altered on-court movements and wrong cognitive (i.e. tactical) choices. For example, Mitchell et al. (1992) have reported that fatigue after a three-hour tennis match play is manifested by a decreased velocity of the serve and longer time to complete tennis pattern shuttle-runs. Girard et al. (2006) reported progressive reductions in maximal voluntary strength (10–13 per cent decrease in quadriceps) and leg stiffness highly correlated with increases in perceived exertion and muscle soreness throughout a three-hour tennis match, whereas explosive strength was maintained and decreased only after exercise. Furthermore, a 16 per cent decrease in knee extensor isometric maximum voluntary contraction torque was observed after a one-hour squash match play (Girard et al., 2010c). The aetiology of muscle fatigue in racket sports is a complex phenomenon (i.e. distinction between temporary fatigue and fatigue occurring in the final stage of a competition) that involves impairment in both neural (suboptimal muscle activation) and contractile (accumulation of metabolites) processes (Girard and Millet, 2008; Girard et al., 2010c). Hot environments and dehydration worsen fatigue, whereas carbohydrate supplementation before or during competitions may delay the development of fatigue (Hornery et al., 2007).

**Future research directions**

Further research in racket sport performance needs to take advantage of technological advances. For example, the Hawk-Eye system (Hawk-Eye Innovations, Basingstoke, UK) is accurate
ball-tracking technology that is applied during real matches rather than being restricted to controlled experiments.

Because the segmental coordination of movement execution may be rearranged with fatigue (Forestier and Nougier, 1998), future experiments should consider changes in kinematics, kinetics or EMG signals of body segments involved in the kinetic chain to explain the decrease in stroke effectiveness during prolonged match play. However, there is more to performance analysis of sport than notational analysis and biomechanics. An expanded array of methods can be used in performance analysis of sport (O’Donoghue, 2010: 2). There have already been examples of other ways of analysing actual sports performance in racket sports. Buscombe et al. (2006) analysed body language, demonstrating that opponent body language could affect the perceptions of a player. Other research using new types of data from actual sports performance includes the research of Poziat et al. (2009), who have analysed verbalisations made during table tennis matches. There is other research into racket sports which is covered elsewhere in this handbook. For example, squash has been used as an exemplar of sport as a dynamic self-organising system (McGarry et al., 2002). Feedback systems for table tennis have been developed using ball impact detection technology (Baca and Kornfeind, 2009) and interactive video analysis of shot types (Leser and Baca, 2009). Further development and evaluation of such systems in all racket sports is another important area for future research.

Finally, the increasing interest in performance analysis in tennis must be expanded to the other racket sports. Future experiments must be done in a context appropriate to game play (specificity of the experimental situation) with, in parallel, a high level of standardisation and reliability of the measures.

Concluding remarks

A considerable volume of research has been done in racket sports performance, with some of the earliest notational analysis research being applied in squash (Hughes, 1998). However, as sports science has emerged, more ambitious studies have used a greater variety of methods in the investigation of different aspects of racket sports. These include kinematic analysis, ground reaction force measures, plantar pressure data, physiological measures and player tracking data.

References


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