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The importance of perturbations in elite squash: An analysis of their ability to successfully predict rally outcome.

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Abstract

This study investigated the presence of perturbations within elite squash through the analysis of critical incidents responsible for successful rally outcome. Thirty one matches from the men's 2011 Australian Open Squash Championships were analysed via a customised Dartfish performance tagging template. The type of critical incident (perturbation, unforced error, un-returnable shot, let/stroke, and miss-hit) was identified relative to shot selection, player/ball landing position and shot accuracy. Logistic regression analysis assessed the strength of predicting the critical incident responsible for successful rally outcome from the identified predictor variables (shot selection, player/ball landing position, and shot accuracy) and whether certain shot types yielded significant contributions towards such outcomes. The results showed that perturbations were identified 238 times (10%), which was noticeably less frequent than the other critical incident categories; un-returnable shots (36%), unforced errors (31%) and let/strokes (23%). A miss-hit occurred once. The predictive abilities of the logistic regression model demonstrated that it was only effective at predicting the un-returnable shot in relation to the identified predictor variables (98.7%, 94.7, 91.4%, and 100% accurate, respectively). Both player and opponent identified the same shots as having a significant contribution towards rally outcome; volley (p <.01), boast/volley boast (p <.01) and drop/volley drop (p <.01 and p <.05 respectively). It was concluded that whilst perturbations are evident in elite level squash, their importance is questionable as they fail to contribute significantly to the outcome of a rally relative to other critical incidents.

Key Words: Performance Analysis, Squash, Perturbations, Dynamical Systems.

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1. Introduction

Recent technological advances have facilitated the development of analytical software that attempts to model, infer or predict the outcomes of a sporting performance (Hughes *et al.* 2007; Travassos *et al.,* 2013). However, to-date, performance analysis research in squash has yet to progress notably beyond the original work of Hughes (1984; 1994; 1996) and McGarry and Franks (1994; 1995; 1996a; 1996b).

Identifying strengths and weaknesses within a performance places emphasis on the key elements necessary to delineate successful outcomes, assuming that the information provided from past observations can go beyond mere description and move towards predicting future performance (Hughes and Franks, 2004, 2008; Laird and Waters, 2008; James *et al.,* 2012). McGarry and Franks (1994; 1995; 1996a; 1996b) believed that past squash performances held useful information regarding preparation for future contests, regardless of the opponent (McGarry, 2006). However, they concluded that a player's shot response was not independent of their opponent and was in fact dependent upon particular player interactions. While consistent behaviours were observed when a player was competing against the same opponent, inconsistent and varied behaviours were identified against different opponents (Murray *et al.*, 1998; Murray and Hughes, 2001). Moreover, if match data obtained from a performance fails to provide useful information regarding the technical and tactical aspects necessary to facilitate increased levels of success during *future* performances, such quantitative methods of analysis initially implemented by McGarry and Franks (1994; 1995; 1996a; 1996b) to predict and model competitive squash performance (e.g. Stochastic Markov Model) could be regarded as ineffective (McGarry and Franks, 1994; McGarry and Perl, 2004; O'Donoghue, 2005; McGarry, 2009).

Contemporary research attempts to address this concern by adopting a *Dynamical Systems Theory,* viewing racket sports as an interaction process in which the sequential context of the game or the situational context of specific situations is considered (*McGarry et al.,* 1999; O'Donoghue, 2009, Glazier, 2010). If game behaviors' emerge spontaneously through the dynamic interactions of players, then it is conceivable that the manner in which performance indicators are currently used to predict sports outcomes are unstable, and the assumption that invariance exists becomes questionable (Garganta, 2009; McGarry, 2009). The ongoing challenge within contemporary analysis is to review how performance indicators are selected and analysed with reference to their application within a dynamical system. Strategies must now focus on the assembly of indicators that distinguish core features within a performance, considering both the opposition and their interaction among individual players and teams (Borrie *et al.*, 2002; Hughes and Bartlett, 2002; Lames and McGarry, 2007; O'Donoghue, 2008).

Viewing racket sports as complex dynamical systems suggests that squash switches between periods of stability (invariance) and instability (variance). The observed invariance of athletic behaviour is a consequence of both players readily forming a relatively stable rally exchange as they wait to capitalise on an attacking opportunity. The dyadic nature of squash has been shown to demonstrate quite distinct patterns of play with regards to player interaction, as they "dance" around the central position of the court in an attempt to defend the "T" position (McGarry and Franks, 2007; McGarry and Walter, 2007; Walter *et al.* 2007; Vučković *et al.*, 2009). However, if a winning outcome is to be reached within a rally, a player must disrupt the rhythmic oscillation to and from the "T" position and the system therefore must be *critically* de-stabilised, resulting in rally cessation (Lames, 2006). It is this identification of critical data, known as perturbation analysis, which is now believed to have the ability to delineate successful sports performances (McGarry *et al.*, 2002; Palut and Zanone, 2005). Hughes *et al.* (2006) aimed to identify what causes perturbations in squash and subsequently created performance profiles of two elite male squash players using these perturbations as predictors of successful performance rather than the typical winner/error profiles normally associated with traditional methods of performance profiling. They concurred with McGarry *et al.*(1999) stating that squash intermittently alternates between stable and unstable states, and it is at the boundaries of these behavioural states that "critical incidents" can be found. That is, they demonstrated that the drop shot (34.7%), volley drop (18.3%) and the boast (20.7%) were the three main shots that caused perturbations within a squash match. They also concluded that they were played predominantly from the back of the court and on the backhand side of their opponent.

While Hughes *et al.* (2006) addressed the cause of perturbation, how the athlete reacts to the perturbation, and the effect of the perturbation on the stability of the system, a major limitation of their research was its failure to identify what makes a perturbation critical. Concentrating on the aspects of a squash match that are by definition "critical" would make analysis more effective, as key information could be provided on the shot type and accuracy needed in order to promote consistent rally success. Despite no effective trends in patterns of play being discovered in the early work of McGarry and Franks (1994; 1995; 1996a; 1996b), it is recognised that consistent outcomes are achieved through different sequences of play within an event (Davids *et al.*, 2003). With dynamic systems analysis hypothesised to hold the key to unlocking the "hidden logic" of sports performance (Garganta, 2009), is it therefore possible that predictable trends *do* exist? If invariance could be demonstrated at critical moments within a performance, independent of the opponent, patterns of play could potentially be established that have the likelihood of predicting successful performance. The purpose of this investigation was therefore to modify the approach of Hughes *et al.* (2006) in order to identify (i) to what extent perturbations are responsible for successful rally outcome, (ii) the cause of a perturbation that leads to a successful rally outcome based on shot selection and shot accuracy, regardless of the opponent, and (iii) whether patterns are present within a critical incident's final three-shot sequence prior to a successful rally outcome.

2. Method

2.1. Data sample

Following Ethical Approval from the University's Faculty of Applied Sciences Research Ethics Committee and informed consent obtained from the English Institute of Sport (E.I.S), 31 matches (16 in round one, 8 in round two, 4 in the quarter-finals, 2 in the semi-finals and the final) were analysed from the men's 2011 Australian Open Squash Championships played under the recently appointed "point a rally" (PAR) scoring system.

2.2. Procedures

All matches were analysed using Dartfish TeamPro, version 4.0.9.0. The squash court was divided into a 4 x 4 positional matrix (Figure 1) and a range of shot types, distributions and critical incidents were identified. Each shot type and critical incident was given written definitions prior to match analysis (Table 1) (Williams, 2012). In an attempt to address the limitations of previous research regarding the inability to identify exactly how accurate a particular shot was, an additional level of ball landing identification was used within the 4 x 4 matrix (Figure 1). An additional tramline system was introduced to the cell matrix and measured a width of 7.5”. Hong *et al.* (1996a) previously reported that a good quality shot was one that remained within half a racket length to the court walls after rebounding, particularly near any of the 4 corners. Any shot landing in cells detached from the walls were identified as a poor shot, regardless of where it landed as it presented the Opponent with a range of attacking options. However, their accuracy remained relatively subjective as their classification was never quantified. The longest acceptable length for the head of a squash racket is now 390mm (15.4 inches) and it is felt that by introducing a tramline width that is representative of half a racket head length would be a good indicator of an effective shot and justifies the use of such a system. For plotting purposes, instead of attempting to accurately mark out 7.68 inches, the before mentioned 7.5 inches was used. As Dartfish does not permit the super-imposition of a template onto the screen while in “Tagging” mode, the cell matrix was superimposed onto the screen using transparent acetate (Sanderson, 1983).

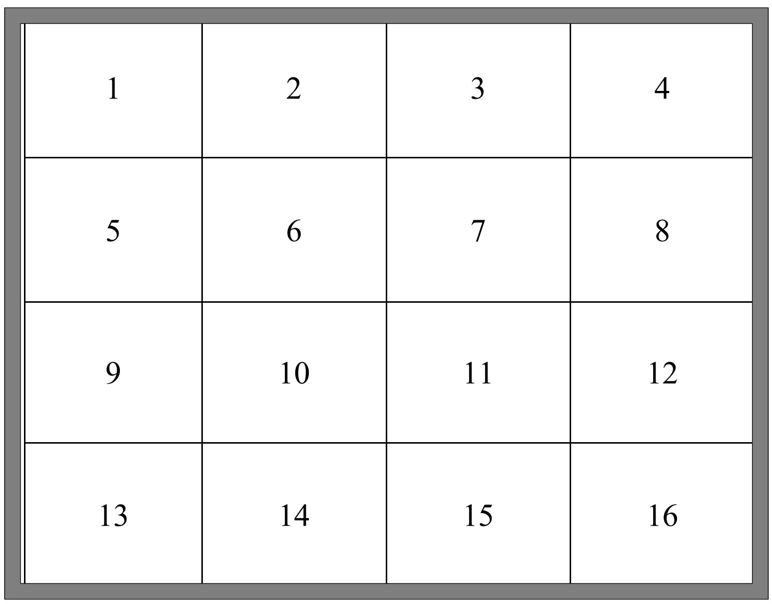


Figure 1. Squash court 4 x 4 positional matrix with additional tramline to identify shot accuracy.

Table 1. Operational definitions.

"Critical Incident" responsible for successful rally outcome	Definition
Perturbation	Opponent loses control of the rally and is pulled out of position prior to the rally winning shot. Indicators of losing control are: • Scrambling (change of pace) towards a different corner of the court in an attempt to reach the ball. • Over stretching when returning the ball indicated by a hand placed on the wall and/or the racket hitting the floor and/or an auditory indication from the Opponent.
Un-returnable shot	Elicits limited response from the Opponent as they fail to successfully return the ball despite appearing to be in optimum position and demonstrating controlled/stable movement. The shot is simply too good to return based on pace/angle/bounce of the ball and/or its close proximity to the court walls.
Miss hit	Contact is made with the ball (either the strings or frame of the racquet) but not as intended. This results in unintentional changes in speed, direction or spin, producing an unpredictable shot placement.

Shot type	Definition
Straight drive	The ball is hit hard and straight off the front wall first. It travels parallel and in close proximity to the side wall preferably finishing deep in the back of the court.
Boast	The ball is played off the side wall at an angle before hitting the front wall.
Back wall shot	The ball is hit hard and high off the back wall, with enough pace to travel the length of the court, striking off the front wall.
Volley	The ball is hit before it touches the floor
Drop Shot	The ball is hit against the front wall first. Played just above the "tin" with very little pace, the aim is to leave the ball at the front of the court close to the front/side wall.
Lob	The ball is played high and soft on the front wall so that it arcs high and lands deep in the back court, ideally in the corners.
Cross court	This occurs when the shots that are normally played straight down the side wall, on the same side that the shot was originally executed (drive, drop, volley, lob), are played to the opposite side of the court (left–right or right–left).

Based on the information and independent variables outlined in Figure 1 and Table 1, a customised performance tagging template was created (Figure 2). To exclude unwanted data, shot selections were not recorded for 'unforced errors', 'miss hits' and 'let/strokes' as they were are not regarded as planned forms of attack. McGarry *et al.* (1999; 2002) identified that squash players were Actors or Reactors/Opponents. Actors are those players who initiate the perturbation and destabilise the rally whereas Reactors/Opponents are those that have to respond to the perturbation in the hope to effectively defend and restore stability to the rally. Let/stroke data collection was not recorded beyond the court position of the players and the acting player responsible for its production. Similarly, unforced error data was not recorded beyond the acting player. Upon rally cessation, the final three shots of each rally were notated and were categorised based on their pre-determined classification. If a perturbation was not accurately identified, the three-shot sequence was still analysed based on the identified critical incident as it was deemed this might hold some importance with respect to possible patterns in player performance. The outcome of the rally denoted the start of the next rally until the contest ended. Once all specified match information was collected, the data were exported to Excel and SPSS (Statistical Package for the Social Sciences) for analysis.

Round	Game	Rally Number	Shots in Rally	Critical Incident	Acting Player	Actor's1st Shot Court Position (Cell Number)	Actor's 1st Shot Selection	Opponent's Court Position (Cell Number)	Actor's 1st Shot Finishing Position (Cell Number)	Actor's 1st Shot Accuracy	Opponent's Return Shot Court Position (Cell Number)	Opponent's Return Shot Selection	Actor's Court Position (Cell Number)	Opponent's Return Shot Finishing Position (Cell Number)	Opponent's Return Shot Accuracy	Actor's Winning Shot Court Position (Cell Number)	Actor's Winning Shot Selection	Opponent's Final Court Position (Cell Number)	Actor's Winning Shot Finishing Position (Cell Number)	Actor's Winning Shot Accuracy
1	1	23	46	3	1	13	16	10	9	2	13	16	10	10	2	14	21	13	4	1
1	3	5	13	5	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	1	8	9	4	2	10	-	10	-	-	-	-	-	-	-	-	-	-	-	-

Coding Key:

Round

1 = Round 1	3 = Quarter-finals	5 = Final
2 = Round 2	4 = Semi-finals	

Critical Incident

1 = Perturbation	3 = Un – returnable s	5 = Unforced error
2 = Miss hit	4 = Let/Stroke	

Player

1 = Player A	2 = Player B

Shot Selection

1 = Forehand straight Drive	16 = Backhand drive
2 = Forehand cross court drive	17 = Backhand cc drive
3 = Forehand boast	18 = Backhand boast
4 = Forehand cc boast	19 = Backhand cc boast
5 = Forehand drop	20 = Backhand drop
6 = Forehand cc drop	21 = Backhand cc drop
7 = Forehand volley	22 = Backhand volley
8 = Forehand cc volley	23 = Backhand cc volley
9 = Forehand volley boast	24 = Backhand volley boast
10 = Forehand cc volley boast	25 = Backhand cc volley boast
11 = Forehand volley drop	26 = Backhand volley drop
12 = Forehand cc volley drop	27 = Backhand cc volley drop
13 = Forehand lob	28 = Backhand lob
14 = Forehand cc lob	29 = Backhand cc lob
15 = Forehand back wall	30 = Backhand back wall
	31 = Serve

Shot Accuracy

1 = Landed within cell boarder system (Tight)	2 = Landed outside cell boarder system (Loose)

Figure 2. Example of customised performance tagging template.

2.3. Intra-observer reliability

The data in Table 2 represents the percentage observed agreement between test-retest measures of the same data source for the chosen performance indicators. This helped in assessing the internal consistency between the analyst and the chosen method of analysis (O'Donoghue, 2007). A 90% level of agreement was selected *a priori* (10% error/disagreement) as being acceptable following the recommendations of Hughes *et al.* (2006) and Reed and Hughes (2006). As the current statistics demonstrate less than a 10% disagreement (error), the tagging template used within this research was deemed to have demonstrated acceptable levels of intra-observer reliability (Hughes *et al.*, 2002).

Table 2. Percentage observed agreement during intra-observer reliability analysis.

Variables	Total Frequency of Recorded Incidents	Total Frequency of Agreed Incidents	Percentage Observed Agreement (%)
Critical incident	192	189	98.44
Acting player	192	192	100
Actor's 1st shot court position	131	124	94.66
Actor's 1st shot selection	85	83	97.65
Opponent's return court position	132	126	95.45
Actor's 1st shot landing position	69	68	98.55
Actor's 1st shot accuracy	85	82	96.47
Opponent's return shot court position	85	82	96.47
Opponent's return shot selection	85	83	97.65
Actor's court position	85	85	100
Opponent's shot landing position	63	62	98.41

Opponent's shot Accuracy	85	83	97.65
Actor's winning shot court position	90	87	96.67
Actor's winning shot selection	90	89	98.89
Opponent's final court position	90	86	95.56
Actor's winning shot landing position	90	86	95.56
Actor's winning shot accuracy	90	88	97.78

In addition to the above, a second reliability assessment was conducted based on the *data sequence* analysis described by Cooper *et al.* (2007). This considers not only the percentage observed agreement for performance indicators (predictor variables), but whether or not they occurred in the same sequence within each rally. It emerged that when analysed across different data sequence groups (entire rally, shot selection, player court position, shot landing position and ball accuracy), 92.7%, 100%, 99.4%, 100%, and 100% of data were correctly identified within ± 1 , respectively, and 99.48%, 100%, 100%, 100%, and 100% of data within ± 2, respectively. Again, on the basis of the suggestions of Cooper *et al.* (2007), observed agreement was set as 90% within a reference value of ± 1 correctly identified variables, and 95% within ± 2). These findings endorse the reliability of the tagging template used within this research.

2.4. Inter-observer reliability

In order for the system to become objective, an inter-observer reliability study was also performed. This helped to demonstrate that any results obtained were independent of an individual observer. The data in Table 3 represents the percentage observed agreement between two performance analysts' measures of the same data source for the chosen performance indicators. Both analysts held an MSc in Performance Analysis, had experience capturing data for the E.I.S and were familiar with Dartfish TeamPro as an operating system. Once again, a 90% level of agreement was selected *a priori* (10% error/disagreement) as being acceptable following the recommendations of Hughes *et al.* (2006) and Reed and Hughes (2006). As the inter-reliability results also demonstrate less than a 10% disagreement (error), the tagging template used within this research was similarly deemed to have displayed acceptable levels of inter-observer reliability (Hughes *et al.*, 2002).

Table 3. Percentage observed agreement during inter-observer reliability analysis.

Variables	Total Frequency of Recorded Incidents	Total Frequency of Agreed Incidents	Percentage Observed Agreement (%)
Critical incident	192	191	99.48
Acting player	192	189	98.44
Actor's 1st shot court position	131	119	90.84
Actor's 1st shot selection	85	83	97.65
Opponent's return court position	132	120	90.91
Actor's 1st shot landing position	69	67	97.10
Actor's 1st shot accuracy	85	81	95.29
Opponent's return shot court position	85	80	94.12
Opponent's return shot selection	85	81	95.29
Actor's court position	85	85	100
Opponent's shot landing position	63	63	100
Opponent's shot accuracy	85	81	95.29
Actor's winning shot court position	90	85	94.44
Actor's winning shot selection	90	87	96.67
Opponent's final court position	90	86	95.56

Actor's winning shot landing position	90	86	95.56
Actor's winning shot accuracy	90	85	94.44

As with the intra-observer reliability analysis, a second assessment was conducted based on the *data sequence* analysis described by Cooper *et al.* (2007). It emerged that when analysed across the different data sequence groups (entire rally, shot selection, player court position, shot landing position and ball accuracy), 92.2%, 99.5%, 96.9%, 100%, and 100% of data were correctly identified within ± 1 , respectively, and 95.3%, 100%, 99%, 100%, and 100% of data within ± 2, respectively. Once again, on the basis of the suggestions of Cooper *et al.* (2007), observed agreement was set as 90% within a reference value of ± 1 correctly identified variables, and 95% within ± 2). These findings further endorse the reliability of the tagging template used within this research.

2.5. Statistical Analysis

Descriptive statistics (frequency of critical incident occurrence; percentage shot selection and distribution; percentage court position) were generated in Microsoft Excel and logistic regression was utilized in SPSS to model the critical incidents responsible for a successful rally outcome from the identified predictor (independent) variables. Specifically, binary logistic regression analysis enabled an assessment of whether the independent variables (shot selection/court location/shot accuracy) were related to the critical incident responsible for rally outcome (perturbation, un- returnable shot, mis-hit, unforced error, let/stroke). Owing to the complexities of the analysis, the independent variables were re-coded and grouped into larger categories. The 31 shots available during a player's shot selection were re-coded into 4 groups; volley, drive, boast/volley boast and drop/volley drop. Serve, lob and back-wall shots were recoded as "missing". Similarly, the 16 different court/shot landing positions available were also recoded into 4 groups; front court, side/middle court, middle court and back court. Using the forward stepwise method, all variables were incorporated into the model until any failed to comply with its specific inclusion criterion regarding its score statistic value (cut-off point was $p < .05$).

3. Results

Figure 3 presents descriptive statistics generated with reference to the critical incidents recorded. Perturbations were identified 238 times (10%), which was noticeably less frequent than the other three critical incident categories. A miss-hit occurred only once and therefore was omitted from the analysis.

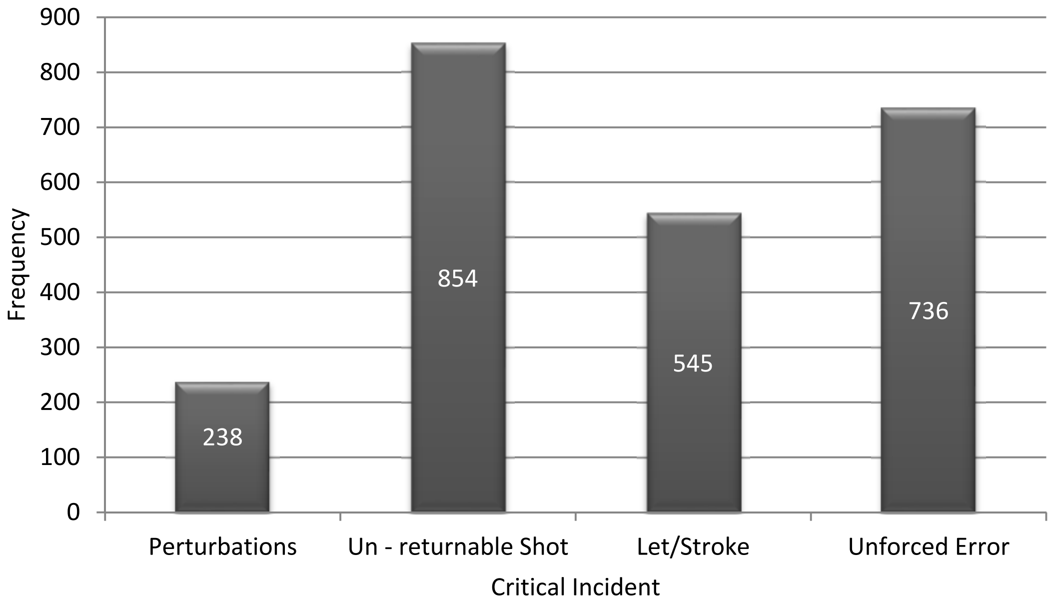
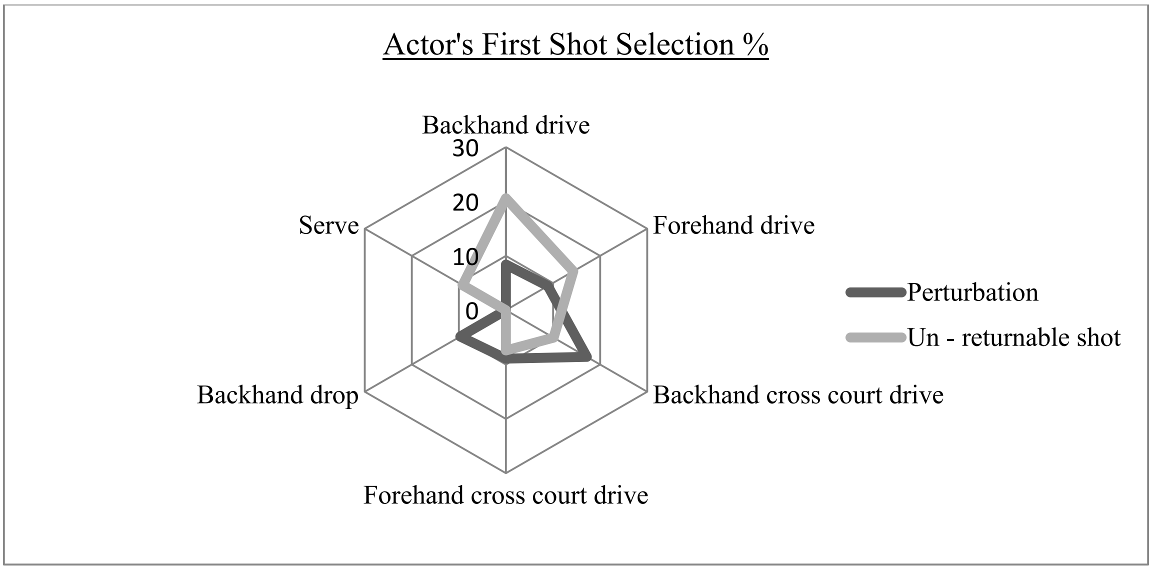
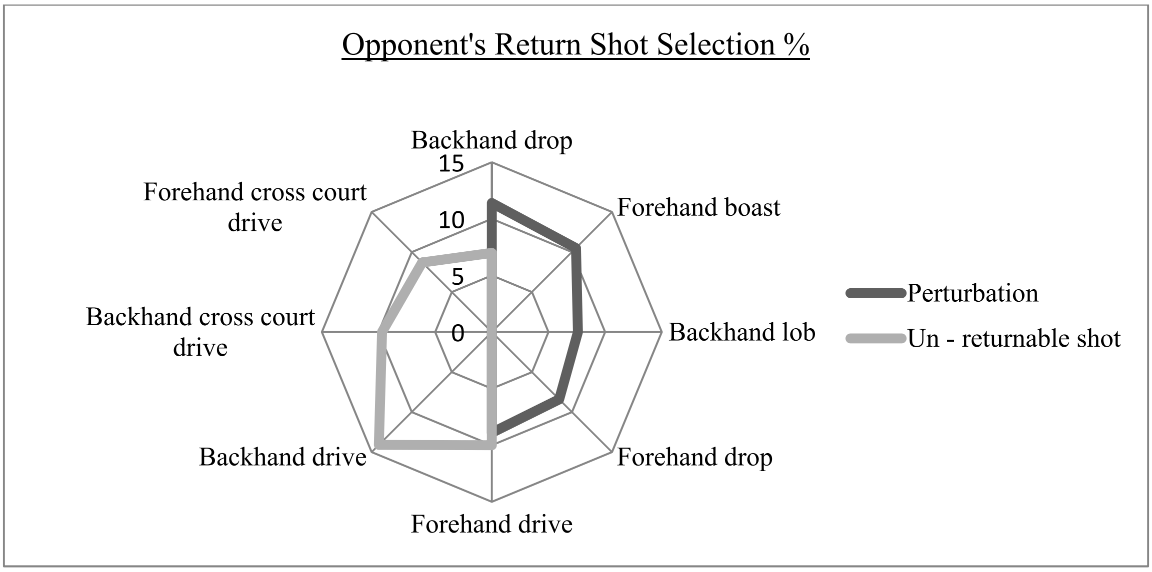


Figure 3. Critical incident occurrence.

Figure 4 displays the breakdown of shot selections as they pertain to both perturbations and un-returnable shots. Shot selections were not recorded for unforced errors, miss-hits or let/strokes as they were not regarded as planned forms of attack and were therefore classed as ‘unpredictable’. The Actor’s ‘Winning Shot’ selections were identical for both perturbation and un-returnable shot rally sequences, with their percentages of execution also similar, particularly the backhand drop (13% and 13.3%, respectively), forehand drive (11.3% and 11.1%, respectively) and forehand drop (9.7% and 9.9% respectively). In comparison, the Actor’s ‘First Shot’ selections and the Opponent’s ‘Return Shot’ selections were distinctly different; Opponent’s “Return Shots” that followed a perturbation rally sequence comprised a variety of shot types but predominantly left the ball at the front of the court; backhand drop (11.4%), forehand boast (10.5%) and forehand drop (8.4%), whereas the Opponent’s “Return Shots” that followed an un-returnable shot rally sequence predominantly left the ball at the back of the court; backhand drive (14.1%), forehand drive (10%), backhand cross court drive (9.7%) and forehand cross court drive (8.7). In contrast, the Actor’s “First Shot” selections following both perturbations and un-returnable shot rally sequences comprised almost entirely shots that placed the ball at the back of the court; backhand drive (20.6%), forehand drive (14.3%), backhand cross court drive (10.1%) and forehand cross court drive (7.4%) Beyond the similarities regarding "back court" shot selection, the only distinct difference between the un-returnable shot and perturbation rally sequences was the exclusive application and exclusion of the serve (9.2% and 0%, respectively) and the backhand drop shot (0% and 9.7% respectively). The choice of "drive angle" also appeared to be dependent on the critical incident. A perturbation rally sequence typically produced a forehand or backhand cross court drive (8.9% and 17.2%, respectively), whereas an un-returnable shot rally sequence typically produced a forehand or backhand straight drive response (14.3% and 20.6%, respectively).





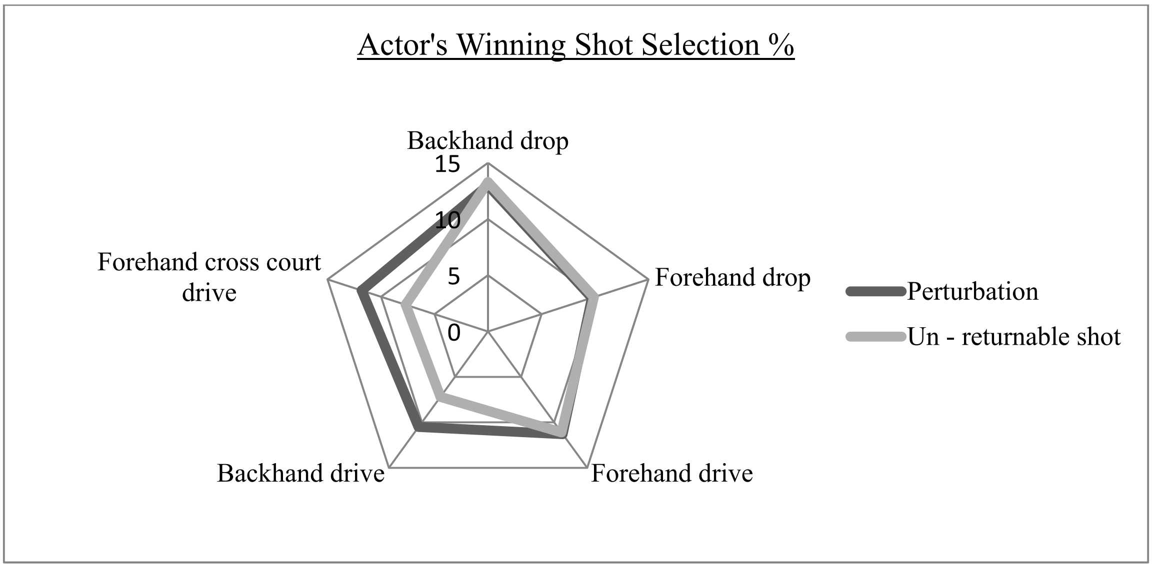
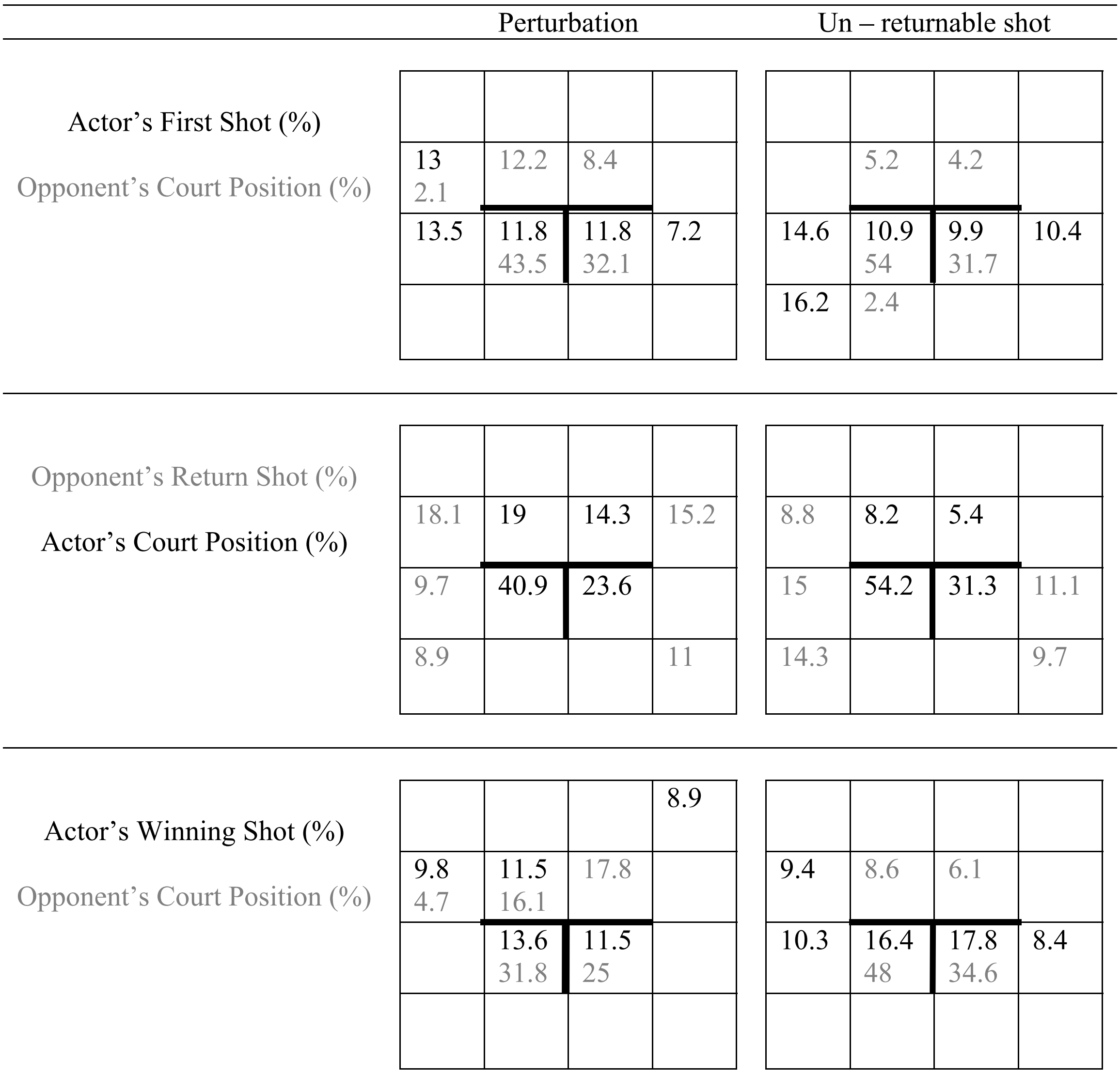


Figure 4. Actor and Opponent top 5 shots during perturbations and un-returnable shots.

Figure 5 shows the five most prevalent court positions in respect of both perturbations and un-returnable shots. Percentage distributions indicate once again that perturbation rally sequences typically produced exchanges further forward in the court than un-returnable shot rally sequences. This was particularly evident for the Opponent's "Return Shot" court position. The Opponent was manoeuvred to the side walls in both circumstances but was forced to move to the front of the court 25% more frequently when responding to a perturbation rally sequence. With regards the defensive positioning of the Actor's and Opponent's when receiving a shot rather than executing one, both exhibited high success rates when returning to the "T" (the central position of the court highlighted in Figure 5). When focusing on the Opponent's Court Position when receiving the Actor's "First Shot", the Actor's Court Position when receiving the Opponent's "Return Shot", and the Opponent's Court Position when receiving the Actor's "Winning Shot" during an un-returnable rally sequence, it was observed that they were able to return successfully to the "T" 95.1%, 99.1% and 97.3% of the time, respectively. However, when players were engaged in a perturbation rally sequence, the Opponent's defensive positioning appeared to decline; specifically, their Court Position at the moment of the Actor's "Winning Shot". During such a sequence, the Opponent's ability to return the "T" at the time of the Actor's "Winning Shot" declined by 6.5% (to 90.7%).



**The top 5 positions were recorded unless < 1%*

Figure 5. Court positions when executing and reacting to the Actor's First Shot, Opponent's Return Shot and Actor's Winning Shot.

Figure 6 highlights that all perturbations and un-returnable shots landed within one of the 12 perimeter cells, demonstrating that they were executed with a relative degree of precision. In terms of the Actor's "First Shot", Opponent's "Return Shot" and Actor's "Winning Shot" ball landing positions, the data also demonstrates that more shots landed in the perimeter cells during a perturbation rally sequence (77%, 80.3% and 85.7%, respectively) than in an un-returnable shot rally sequence (76.6%, 67.7% and 78.9%, respectively). In addition, it was obvious that perturbation rally sequences produced exchanges that occurred predominantly in the front of the court (45.3%, 80.3% and 62.1%, respectively), which was noticeably more frequently than the front court distribution produced during an un-returnable rally sequence (21.9%, 57.9% and 60.6%, respectively).

	Perturbation				Un – returnable shot			
Actor's First Shot (%)	21.5			15.5	14			7.9
	9							
	10.7			21	25.6			20.9
					8.2			
Opponent's Return Shot (%)	27.9	7		29.1	20.6			16.3
	9.3			7	10.7			10.3
					9.8			
Actor's Winning Court (%)	22.4			24.5	24.8	7.1		28.7
	7.6			7.6				
	14.3			9.3	8.9			9.4

Figure 6. Top 5 shot landing positions of the Actor's First Shot selection, Opponent's Return Shot selection and Actor's Winning Shot selection.

Shot accuracy was seen to be somewhat poor (Table 4) given that both critical incident scenarios produced disadvantageous ratios. However, while similar shot accuracy percentages were produced by both critical incident types, it was notable that after the Actor's "First Shot", the accuracy ranged from 62.4 - 69.9% ('loose') and 30.1 - 37.6% ('tight'). When the Opponent engaged in a return shot, the accuracy markedly decreased, producing a range of 86.1 - 92.4% loose shots and a limited range of 7.6 - 13.9% tight shots. Conversely, the Actor's "Winning Shot" accuracy increased to a positive range of 52.3 - 53.2% tight shots and 46.8 - 47.7% loose shots following the poorly executed return shot from the Opponent. .

Table 4. Shot accuracy.

Critical Incident	Actor's first shot finishing accuracy		Opponent's return shot finishing accuracy		Actor's winning shot finishing accuracy	
	Tight	Loose	Tight	Loose	Tight	Loose
Perturbation	37.6%	62.4%	7.6%	92.4%	52.3%	47.7%
Un-returnable shot	30.1%	69.9%	13.9%	86.1%	53.2%	46.8%

Table 5 demonstrates that when the binary logistic model was applied to the four predictor variable groups (shot selection/court position/ball landing position/shot accuracy), it was effective at predicting the un-returnable shot (98.7%, 94.7, 91.4% and 100% accurate, respectively), but not the perturbation (1.9%, 25.6%, 24.3% and 0% accurate, respectively).

Table 5. Predictive success of critical incidents.

Predictor variables	Perturbation Success (%)	Un – returnable Shot Success (%)	Overall Success (%)
Shot Selection	1.9	98.7	76.4
Court Position	25.6	94.7	78.7
Ball Landing Position	24.3	91.4	72.1
Shot Accuracy	0	100	76.6

With regard to shot selection (Table 6) all predictor variables except the Actor's "Winning Shot" selection were included in the final model. Both the Actor's "First Shot" selection and the Opponent's "Return Shot" selection identified the same shots; volley ($p < .01$), boast/volley boast ($p < .01$) and drop/volley drop ($p < .01$ and $p < .05$, respectively) as having a significant contribution to rally outcome. Only the predictor variables that examined Actor's court position in relation to their "First Shot" and "Winning Shot" execution and successful rally outcome were viewed as significant (Table 7). Two of the Opponent's "Return Shot" court positions were significant ($p < .05$) predictors of successful rally outcome (return shots from the back and shots from the side-middle and middle of the court), whereas those returned from the front of the court were not ($p = .34$).

Table 6. Binary logistic regression of shot selection.

	B (SE)	Residual Chi-Square	Model Chi-Square	Wald	Sig.
Initial Model					
Constant	1.21 (.09)	79.69	-	176.75	.000**
Intervention Model	-	-	78.28	-	.000**
Actor's First Shot -Volley	-	-	-	26.54	.000**
Actor's First Shot - Drive	.02 (.30)	-	-	.00	.953
Actor's First Shot - Boast/Volley boast	−1.11 (.42)	-	-	7.05	.008**
Actor's First Shot - Drop/Volley drop	−1.26 (.31)	-	-	13.60	.000**
Opponent's Return Shot - Volley	-	-	-	22.88	.000**
Opponent's Return Shot - Drive	−1.99 (1.02)	-	-	3.78	.052
Opponent's Return Shot - Boast/Volley boast	−3.00 (1.03)	-	-	8.47	.004**
Opponent's Return Shot - Drop/Volley drop	−2.51 (1.04)	-	-	5.83	.016*
CONSTANT	3.88 (1.04)	-	-	13.95	.000

*$p < .05$ **$p < .01$

Table 7. Binary logistic regression of court position.

	B (SE)	Residual Chi-Square	Model Chi-Square	Wald	Sig.
Initial Model					
Constant	1.20 (.75)	159.77	-	257.12	.000**
Intervention Model	-	-	144.81	-	.000**
Actor's First Shot - Front Court	-	-	-	36.78	.000**
Actor's First Shot - Back Court	1.30 (.38)	-	-	11.71	.001**
Actor's First Shot – Side Middle Court	1.18 (.38)	-	-	9.40	.002**
Actor's First Shot - Middle Court	2.20 (.40)	-	-	29.61	.000**
Opponent's Return Shot – Front Court	−.34 (.35)	-	-	.92	.339
Opponent's Return Shot – Back Court	-	-	-	18.24	.000**
Opponent's Return Shot – Side Middle Court	−.42 (.18)	-	-	5.33	.021*
Opponent's Return Shot – Middle Court	.67 (.28)	-	-	5.60	.018*
Actor's Winning Shot – Front Court	−2.77 (.47)	-	-	34.14	.000**
Actor's Winning –Back Court	-	-	-	52.99	.000**
Actor's Winning Shot – Side Middle Court	−1.30 (.45)	-	-	8.31	.004**
Actor's Winning Shot – Middle Court	−1.37 (.44)	-	-	9.60	.002**
CONSTANT	1.35 (.57)	-	-	5.6	.018*

*$p < .05$ **$p < .01$

The Actor's "First Shot" landing in the front and the middle of the court was seen to be a significant ($p < .001$) predictor of successful rally outcome (Table 8), unlike shots to the back and side middle of the court ($p = .06$ and .08, respectively). Conversely, of the Actor's "Winning Shots", those that landed in the back, side middle and middle of the court significantly influenced rally outcome ($p < .05$). Shots to the front of the court offered little to the rally outcome ($p = .76$). The landing positions of the Opponent's shots were predominantly non-influential ($p > .05$), the exception being shots landing in the back of the court ($p < .01$).

Table 8. Binary logistic regression of shot landing position following shot execution.

	B (SE)	Residual Chi-Square	Model Chi-Square	Wald	Sig.
Initial Model					
Constant	.91 (.09)	62.12	-	98.69	.000**
Intervention Model	-	-	69.64	-	.000**
Actor's First Shot - Front Court	-	-	-	20.78	.000**
Actor's First Shot - Back Court	.38 (.21)	-	-	3.31	.077
Actor's First Shot - Side Middle Court	2.03 (1.06)	-	-	3.67	.055
Actor's First Shot - Middle Court	2.25 (.54)	-	-	17.18	.000**
Opponent's Return Shot – Front Court	−.73 (.41)	-	-	3.26	.071
Opponent's Return Shot – Back Court	-	-	-	15.07	.002**
Opponent's Return Shot - Side Middle Court	.13 (.43)	-	-	0.88	.766
Opponent's Return Shot – Middle Court	−.18 (.57)	-	-	.10	.748
Actor's Winning Shot – Front Court	−1.15 (.65)	-	-	3.15	.076
Actors Winning –Back Court	-	-	-	10.60	.014*
Actor's Winning Shot – Side Middle Court	−1.59 (.65)	-	-	6.00	.014*
Actor's Winning Shot – Middle Court	−2.00 (.83)	-	-	5.79	.016*
CONSTANT	2.22 (.74)	-	-	9.00	.003**

*$p < .05$ **$p < .01$

In Table 9, all of the predictor variables, with the exception of Actor's "Winning Shot" accuracy, were included in the final model to predict successful rally outcome. Clearly, "Loose" shots were significant with regards to the Actor's "First Shot" ($p < .05$), whereas "Tight" return shots were meaningful on the part of the Opponent ($p < .05$).

Table 9. Binary logistic regression of shot accuracy in relation to the squash ball's proximity to the court walls at the first bounce.

	B (SE)	Residual Chi-Square	Model Chi-square	Wald	Sig.
Initial Model					
Constant	1.19 (.07)	11.35	-	255.41	.000**
Intervention Model	-	-	11.87	-	.003**
Actor's First Shot Accuracy - Loose	.33 (.16)	-	-	4.60	.032*
Opponent's Return Shot Accuracy - Tight	.67 (.27)	-	-	6.37	.012*
CONSTANT	.89 (.13)	-	-	49.48	.000**

*$p < .05$ **$p < .01$

4. Discussion

This study has demonstrated that critical incidents could be reliably identified within elite men's squash and that they individually exhibit particular patterns of play regarding shot selection, distribution and accuracy. Moreover, in line with the findings of McGarry *et al.* (1999; 2002); Palut and Zanone (2005); McGarry (2006) and Hughes *et al.* (2006), the presence of perturbations was observed, albeit they were infrequent and offered little contribution to the prediction of successful rally outcome compared to other critical incidents, such as un-returnable shots. On this basis, it seems that perturbation analysis is not a valid predictor of squash performance.

Examining the descriptive statistics, it was demonstrated that when an Actor's "First Shot" and an Opponent's "Return Shot" were classified as un-returnable, they predominantly left the ball at the back of the court. The top three shots for both the Actor and Opponent in this situation both comprised of the same shot types; backhand drive (20.6% and 14.1%, respectively), forehand drive (14.3% and 10%, respectively) and backhand cross court drive (10.1% and 9.7% respectively). These shots are characteristic of a typical rally exchange as they engaged in a defensive and stable trading of shots while awaiting a weak shot by their Opponent that invited an attacking shot to the front of the court. This supports the views of Hong *et al.* (1996b) and Hughes *et al.* (2006) that such a "pressure and attack" approach was often adopted owing to the majority of squash players being right handed and their tendency to exploit and overload the backhand of their Opponent. Conversely, when the Actor's "First Shot" and the Opponent's "Return Shot" were successfully incorporated into the binary logistic regression model, it emerged that the most significant shots when predicting successful rally outcome (for both the Actor and the Opponent) were the volley, boast/volley boast, and drop/volley drop. Indeed, this also concurs with Hong *et al.* (1996b) and Hughes *et al.* (2006) who identified the drop, volley or volley drop, and boast as the most effective shots associated with an attack.

The current analysis highlighted that while a high number of successful rally outcomes came following what could be perceived as a ‘comfortable rally exchange’, these rallies could not be used to predict future success when applied to forthcoming competitions against different Opponents. That is, the final shot was simply too good for retrieval and was independent of the shots that preceded it. While this study does not provide a direct examination of the influence and evolution of deception, perception and anticipation, it is recognised that players who are able to disguise strokes may be able to significantly reduce the effectiveness of an Opponent’s ability to anticipate shot selection/distribution. This deception in turn reduces their ability to successfully return the shot. To date, most research has focused on how skilled athletes use advance cues to successfully anticipate an Opponent’s actions. However, a neglected topic is an assessment of the ability of athletes to disguise such cues by delaying their onset, thus limiting an Opponent’s opportunity to successfully anticipate future actions (Rowe *et al.*, 2009). Nevertheless, certain shot types were seen to offer significant contributions to the prediction of successful rally outcome. The “First Shot” of an Actor within the final three-shot rally sequence (volley, boast/volley boast and drop/volley drop) exhibits similar characteristics to the winning shots identified by Hong *et al.* (1996b), and the perturbing shots identified by Hughes *et al.* (2006). This would suggest that an attempt was made by the Actor to perturb the rally through consistently using the same combination of shots to put their Opponent under pressure. However, the loss of control traditionally exhibited by the Opponent when the stability of a rally has been perturbed was not identified. This intimates that it is irrelevant where the Opponent is on court; they have every opportunity to successfully return the ball, providing they have appropriate levels of fitness and proficiency towards “reading” the game (Girard *et al.*, 2007).

With regards to the importance of shot accuracy, it was noticed that what was expected to happen did not actually occur. That is, it was expected that the Actor’s “First shot” would be “tight” in order to move the Opponent out of position, putting pressure on his return shot and yielding a “loose” ball, allowing the Actor to profit with a “Winning Shot”. This was not the case. In its current state, the analyst used the cell boarder system to indicate accuracy regarding where the ball landed, not finished. As a result, despite proving to be a reliable system when identifying and coding performance variables, the data produced could have been potentially open to misinterpretation, if the recipient of the data (analysts/coach/player) had poor knowledge of the technical and tactical aspects of squash performance. What might be perceived as a “loose” shot from the Actor may actually be a result of a passing shot (cross court volley) that aims to finish “tight” in the back corners of the court. In order to so, the ball must first bounce closer to the middle of the court (cells 5, 8, 9 and 12). Conversely a cross court shot that was defined as “tight” may actually be considered a weak shot as the ball is travelling towards the wall. As a result, the ball would inevitably bounce close to the wall, strike the wall and drift back into open court. Equally, if the ball is travelling in the direction of the wall (straight drive), providing that the ball is of good length, the ball will bounce parallel to the side/middle of the court, remain close to the wall and finish tight within the back of the court. In this situation, a shot identified as tight would be accurate and represent a strong quality shot. The introduction of this system is regarded as advantageous as it offers a greater insight into the level of accuracy required to delineate successful performance. However future use of this system would benefit from a redefinition that differentiates whether or not the shot was traveling towards the wall (cross court) or along the length of the wall (straight).

To this point, the analyses have identified that perturbations failed to offer a significant contribution to the prediction of successful rally outcome that could be applied to discrete competitions, against different Opponents. However, while the use of un-returnable shots, by definition did perturb the stability of a rally through effective shot selection, court position and ball placement, the loss of control (scrambling, over stretching) traditionally exhibited by the Opponent during such a perturbed state was not observed. In racket sports the main task of the defending player is to predict both the direction and velocity of an Opponent's forthcoming stroke. This is achieved by extracting information arising from the events before the Opponent strikes the ball and traditionally involves specific information of the pre-contact movement patterns of the Opponent and information related to stroke probabilities (Abernethy *et al.*, 2001). Various studies within contemporary research have examined the kinematic characteristics of racket sports and the essential "pick-ups" required to facilitate expert perception and anticipation (Shim *et al.*, 2006; Abernethy and Zawi, 2007; Triolet *et al.*, 2013). Shim *et al.* (2006) concluded that players were able to identify shot type but were less accurate in identifying stroke direction. Abernethy and Zawi (2007) support these findings stating that the defining characteristics of expert performance was their unique ability to pick up relevant information from the localised kinematics of the racket and the lower body alongside information derived from the movements of the upper body and the arm. Information is believed to be extracted between 160 ms prior to the Opponent making contact with the ball and 160 ms after the ball has been struck. Triolet *et al.* (2013) recognized that this was a sliding scale between anticipation (based on uncertain information that has yet to occur resulting in some errors during response) and reaction (based on certain information resulting in accurate responses). They identified that the transition between anticipation and reaction occurred 140-160 ms after the ball was struck. Future recommendations now state that by increasing the effectiveness of information pick up based on significant, context-specific kinematics, a player may be able to bring the transition between anticipation and reaction closer to the moment of ball strike, thus improving their control and positioning during a rally as a consequence of increasing the time available to reach the ball. These findings help to further explain the lack of successful perturbation identification. It is conceivable that the recent research into the anticipatory and perceptive skills of an athlete has facilitated improvements in reaction time and perceptive/anticipatory cues within a squash player. These increased levels of perception and reaction would therefore appear to remove, or at least significantly reduce, the loss of control and destabilisation traditionally observed when identifying perturbations.

Certain shot patterns within an un-returnable shot sequence demonstrate a significant contribution to predicting successful rally outcome (volley, boast/volley boast and drop/volley drop). The significance of the Actor's "First Shot" in the sequence and the Opponent's "Return Shot" suggest that sequences of events are set in motion that produces a rally outcome through perturbing the stable state of play. However, the perturbation that took place was not accurately observed. Nevertheless, whether the player appeared to arrive at the ball without control (perturbation) or with control (un-returnable), the winning shot was never successfully returned. The objective in squash is to put the ball where the Opponent isn't by placing the greatest distance between them and the ball. A high quality shot from the Actor places the Opponent in a position (regardless of the levels of control that may be exhibited upon approach) where, unless a similar shot is executed with equivalent levels of accuracy, a loss of point will result. Akin to a game of chess when a sequence of events is initiated that places all the pieces in the optimum position to force check mate, an Actor places their Opponent in the most difficult court position based on the distance required to successfully reach the ball. Some players may scramble to get to this point whereas some players may continue to demonstrate control. However at the point of the rally winning shot, both sets of critical incidents utilise the same winning shots to produce a rally outcome. Although the winning shots for both critical incidents were not included within the predictive model, the descriptive statistics demonstrate that the Actor's "Winning Shot" selections (Figure 4) were identical for both perturbation and un–returnable shot rally sequences, with their percentages of execution also demonstrating similarities; particularly the backhand drop (13% and 13.3% respectively), forehand drive (11.3% and 11.1% respectively) and forehand drop (9.7% and 9.9% respectively). In addition, inferential statistics did state that the winning court position and ball landing position offered a significant contribution to the predictive model. This suggests that the final shot selection is irrelevant providing the previous shot put the ball in the optimum court position, which provides an opportunity to capitalise on a weak return from their Opponent.

Beyond the potential benefits previously identified regarding the redefinition of the cell boarder system, there was one relevant limitation identified within this study. It was assumed that if a perturbation was identified as successfully producing a rally outcome, it would last a maximum of three shots; otherwise it was identified as regaining stability. This was based on Hughes *et al.* (2006) who stated that if a rally did manage to regain stability following a perturbation then the majority of the time it happened only once and took between one and three shots to do so. This may be a false premise. It could be viewed that if a rally regained stability it would do so within one and three shots from the moment of perturbation, however, if it did not recover, it is conceivable that the Opponent remained out of control for a greater number of shots. This presents the possibility that many of the rally outcomes were a consequence of perturbations but were not correctly identified because they took place several shots before the point of analysis.

5. Conclusions

This study identifies that perturbations exist but questions their importance within performance analysis as they failed to contribute significantly to the outcome of a rally relative to other critical incidents. A possible explanation for the scarcity of perturbation occurrence relative to the more frequently occurring critical incidents (un-returnable shot, unforced error and let/stroke) is the higher levels of perception/anticipation amongst contemporary elite squash players compared to novice players or non-racquet based sports players. Using tennis as an example, Triolet *et al.* (2013) states that by utilising information obtained from kinematic characteristics of their Opponent, players have shifted the transition between anticipation and reaction closer to the moment of ball strike, increasing the time available to reach the shot. It could be implied that perturbation identification would be more prevalent amongst non-elite, county/club level players as they do not yet possess the perceptive skills that allow recovery and successful returns from the majority of rally situations.

Subtle “perturbations” are still suggested to have occurred within the rally through the use of disguise and superior positional shots from the Actor, which pulled the Opponent to an area of the court that didn’t allow a successful return to be produced. This suggests that perturbation classification may need to be redefined to account for the various subtleties that have been exhibited within this research. The use of time-motion analysis to track movement and alterations in speed/direction of movement may be better suited to identify such incidents that perturb a rally. Used in conjunction with video footage to accurately code the shot types, court positions, ball landing positions and shot accuracies, it may be possible to identify more easily the differences between critical incidents that go beyond mere observation and the factors that facilitate their initiation.

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