USING PERTURBATIONS IN ELITE MEN'S SQUASH TO GENERATE PERFORMANCE PROFILES.

MICHAEL T. HUGHES*, MEGAN HOWELLS & MIKE HUGHES****,
***ENGLISH INSTITUTE OF SPORT, NORTH WEST REGION, MANCHESTER, UK.**
****CPA, UWIC, CYNCOED, CARDIFF, UK. CF26 2XD.**

1 Introduction

Dynamical system theory was developed from physical principles of pattern formation to explain how order emerges in open systems without regulation being imposed by some executive (Hodges et al., 1998). Kelso (1999) explained the phenomenon of dynamic systems as how a given pattern persists under various environmental conditions (stability) and how it adjusts to changing internal or external conditions (adaptability). Examples of dynamic systems are found in physical systems, like the reaction of fluids subjected to heat, as well as social systems like a dynamic interaction of two players in a squash rally (Hodges et al., 1998). Sport can be seen as an open system that exists in a dynamic equilibrium or stable state. An open system displays rhythmical patterns and often displays invariant behavioural characteristics, it relates constantly with its environment, exchanging energy, matter and information useful for maintaining its organisation (Grehaigne, 1996). Team sports such as football demonstrate these rhythms, a team will gain possession, sustain some passes and gain territory, this cycle is broken either by an act of poor defence or good attack. Although there are other factors to consider such as the environment and whether the team is complete.

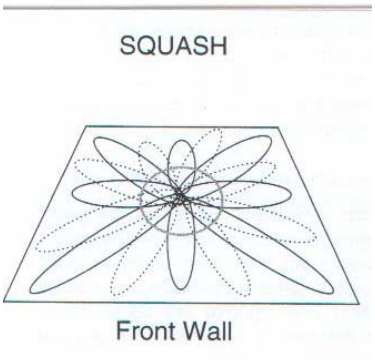

Figure 1. Oscillation of players around the 'T' in a squash game (McGarry, 2005)

A sport that lends it self strongly to the dynamical system theory is squash as the game is always played between two players, therefore the behaviour of one directly affects the behaviour of the other. An integral aspect in the tactics of squash is the control of the 'T' area, and players will circle each

other rhythmically during a rally, as they attempt to gain supremacy, control of this area. This movement generated the idea that the spatial temporal data that describe the interactions within squash are the result of a coupling relation between players oscillating on a common locus (McGarry, 2005). In order to control the rhythm of the game, it is essential to attempt to keep your opponent under pressure and not in control of the 'T' (Pearson, 2001). Squash match play intermittently alternates between stable and unstable behaviour, and it is at the boundaries or transition points of these behaviour states that 'critical incidents' are most likely to be detected (McGarry et al., 1998b). These system transitions are key behaviours within the system that cause a change from a stable rhythm to unstable behaviour. These system transitions can also be called perturbations, and can be used to provide a useful system descriptor and possibly provide information related to winning performance (Hodges et al., 1998).

A perturbation exists in an open system where the usual stable rhythm of play is disturbed by extreme elements of high or low skill, which consequently result in a particular outcome (Hughes and Reed, 2005). Concentrating on the aspects of the match that are by definition critical would make analyses not only easier but far more relevant to sports performers. Analysing whole game patterns in sport may submerge the important events in that sport under the vast amount of general data gathered (Hughes et al., 1998a). The perturbation theory is attractive since it can mean that analysts can focus on a much smaller body of data, so that instead of examining thousands of bits of data that make up a match, attention can be centred on what are considered to be the important events in a match (Hughes et al., 1997).

Hodges et al. (1998) investigated whether system disturbances could be reliably detected across observers of different skill level. Specifically the task was for observers to identify shots that perturb the system from stability to instability and from instability to stability. The study found that both novice and expert squash players could reliably identify system perturbations, although there was higher agreement within expert groups. This reinforces the fact that perturbations exist, and that a game of squash changes from stable to unstable, it also shows us that perturbations are easy to identify. McGarry et al. (1998b) also investigated whether squash moved from a stable to an unstable environment. They evaluated 60 rallies to identify the shots that mark the behavioural transition. The shot perceived to mark the transition form stable to unstable behaviour was called a perturbation onset and the shot perceived to change the system from unstable to stable behaviour was called a perturbation offset. The results showed that the most common causes for the perturbation onsets are strong shots and weak shots, which accounted for 85% of all causes.

Hughes et al. (2000b) raised an important fact that not all perturbations are followed by a critical incident, and sometimes play can revert to its normal rhythm. Also not all critical incidents are preceded by perturbations, sometimes a player may just miss-hit a ball. McGarry et al. (1999), found evidence of multiple perturbations showing that the system does recover from instability in some cases, and reverts again to stability as evidenced by

the next perturbation in the same rally. Squash has a strong tradition for notational analysis. Profiling within the sport is highly sophisticated (Hughes and Robertson, 1998; Hughes et al., 2000) and further research in squash is continually ongoing. McGarry and Franks (1998a) found that squash is a dynamic system and other research (Grehaigne 1996) has found evidence that soccer and other sports also display these qualities. If then performance profiles were created that were based on those events that caused perturbations of the rallies, would these profiles, and therefore that tactical and technical messages in these data, differ from those created from all the shots collected from several matches (Murray and Hughes, 2001)? And if so, would these differences be important to both the sports science and the coaching communities?

The purpose of this investigation is to build performance profiles of elite male players from perturbations and examine whether these are different profiles from those created by more traditional methods.

1.2 Aims

1. To identify what causes perturbations in squash.
2. To create performance profiles of two elite male players using perturbations.

1 2 Method

2.1 System

A hand notation system for squash was devised, in order to develop performance profiles using perturbations of elite male squash players. The system produced data (see figure 2) including, whether a perturbation occurred for or against the player, where in the rally it occurred, the shot and cell from which it occurred, whether or not the rally regained stability and after how many shots. The rally end shot, cell and total number of shots in the rally were also recorded as the rally end shot could be considered the ultimate perturbation.

Matches were analysed on DVD through a laptop, in order to facilitate the use of pause and rewind on the DVD player. This ensured all relevant details were analysed and reduced the amount of errors to a minimum. Once the data were gathered, they were compared to England Squash SWEAT (simple winner error analysis technique) data, for each player both where they played their winners and errors from and where their opponents played them.

Rally number	Perturbation for	Perturbation against	Number of shots in rally at that point	Cell	Shot	Gain stability?	How many shots?	Rally end shot?	Winner/ error	Cell	Player	Total number of shots

Figure 2. Hand notation system used for collecting Perturbation data.

The squash court was divided into a 4 x 4 cell, labelled 1 – 16 (figure 3), this was the same as that used by Murray and Hughes (2001). Intra observer reliability was performed to ensure that the researcher was correctly identifying perturbations. One game was analysed on three separate occasions, the results gathered were put into spreadsheets and compared using an absolute measure of error calculated in the form of percentage differences (Hughes et al., 2004). For this study, an error difference of 10 % will be deemed acceptable.

$$\% \text{ error} = [\sum(\text{mod}(V1 - V2))/ V_{\text{tot mean}}] \text{ X } 100\%$$

Where mod is the modulus and $\sum$ indicates the sum of the overall percentage error, and Vtot mean is the mean of the total variables measured.

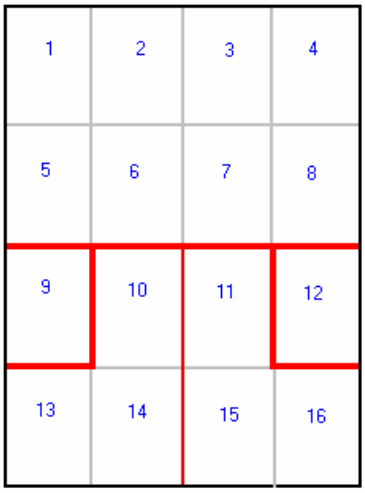

Figure 3. Squash court cell, used to record position of shot.

When a perturbation occurred, the DVD was paused and rewound to when the shot happened. The researcher recorded whether the player being analysed caused the perturbation or had a perturbation caused against them. The number of shots in the rally that had taken place, the shot used using the key, and the cell from which it was played were also notated at this point. The DVD was resumed, and the researcher continued counting the number of shots played. If stability was resumed, two or more consecutive shots were played which returned the rally to it original rhythm, then the number of shots it had taken to do so was notated. The researcher then waited for another perturbation to occur. If after a perturbation the rally did not regain stability and a rally end shot occurred then the researcher notated after how many shots the perturbation occurred, the rally end shot, the cell it was played from, and the total number of shots in that rally.

2.2 Data population

Two players were used for analysis, both are international, right handed and ranked in the top 10 in the world. Only competitive matches were used, to

allow a true reflection of their game, the games were videoed with permission from the players on the professional circuit.

3.5 Data processing

Data analysis was conducted using Microsoft Excel, all raw data were put into Excel, where means and percentages were calculated, for type of shot used to create a perturbation, type of shot used which caused a perturbation against the player, the cell that a player was more likely to cause a perturbation from, and one where they left spaces for perturbations to be caused against them. The analysis also included whether players caused more or less perturbations when they were winning or losing, and if players always won off their perturbation. Whether a rally gained stability was also examined, and how often this occurred. The data gathered were non parametric so Chi square statistical analysis was used for comparisons.

3 Results and discussion

3.1 Reliability

Considerable training was necessary to become consistent with the system, after which an inter-operator reliability study showed that definition of the perturbation by position had 5.8% error, for or against the player, 0%error, shot type, 5.8% error, whether the rally regained stability or not, 0% error and which player won the rally, 0% error.

3.2 Normative profiling

Hughes and Reed (2005) investigated performance profiling using perturbations in football and stated that a minimum of eight games is required for the construction of repetitive database. It is important to ensure a normative profile has been reached, otherwise statements about performance can be inaccurate (Hughes et al., 2001). Four matches were analysed for each player, as this is how many matches England Squash uses to create a data base so this is deemed to be acceptable. Although twelve matches were analysed in total they could not be joined, as there were three different players. The cumulative mean stabilised to within +/- 10 % of the mean of the overall four matches in ten out of the fifteen variables investigated.

1.1 3.3 General results

The data produced by the system agree with McGarry and Franks (1995) that perturbations do exist in squash and can be reliably identified. From the results (figure 5) it is evident that drop (34.7), volley drop (18.3) and boast (20.7) are the three main shots that cause perturbations in a squash match. These findings are very similar to Hughes et al. (1985, 2000c) who

concluded that boast, straight drop and volley short are the three main shots to move an opponent to the front of the court. By comparing these two findings it can be suggested that players going short more often than not cause perturbations.

This study found that once a perturbation occurred, it was more than likely to lead to a critical incident rather than regain stability, these findings are consistent with Hodges et al. (1998) and McGarry et al. (2002) who found that the shots that cause instability are key athletic behaviours in determining the rally outcome and causing critical incidents. Although while conducting this study the researcher noted that as the match progressed, players became fatigued and the rallies were less likely to stabilise. If a rally did stabilise then the majority of the time it only stabilised once, and took between one and three shots to stabilise. Although on one occasion a rally stabilised seven times before a critical incident occurred. It could also happen that a rally lost its rhythm for eleven plus shots before regaining stability. These findings back up McGarry et al. (1999) that there is evidence of multiple perturbations and that rallies go from stability to instability.

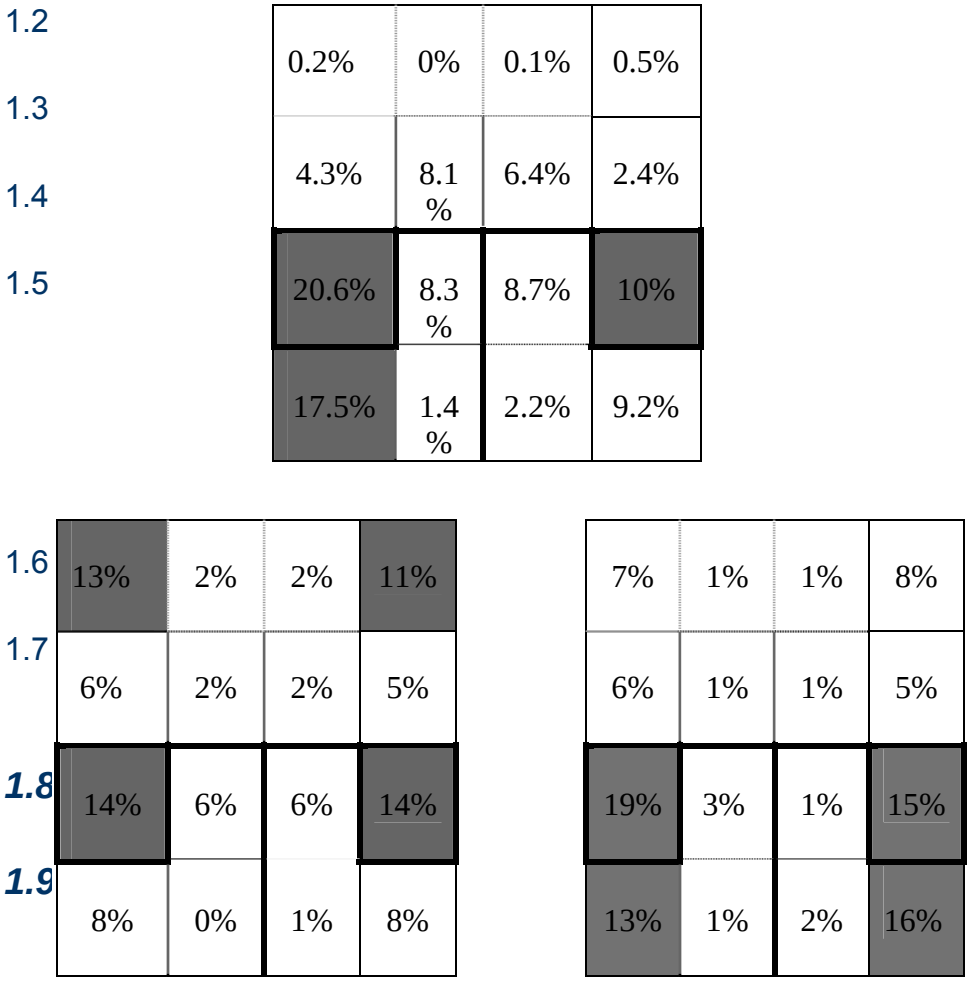

Figure 4. Performance profiles for male squash, top is where players play perturbations from and bottom left is England Squash's winner distribution, and right error distribution.

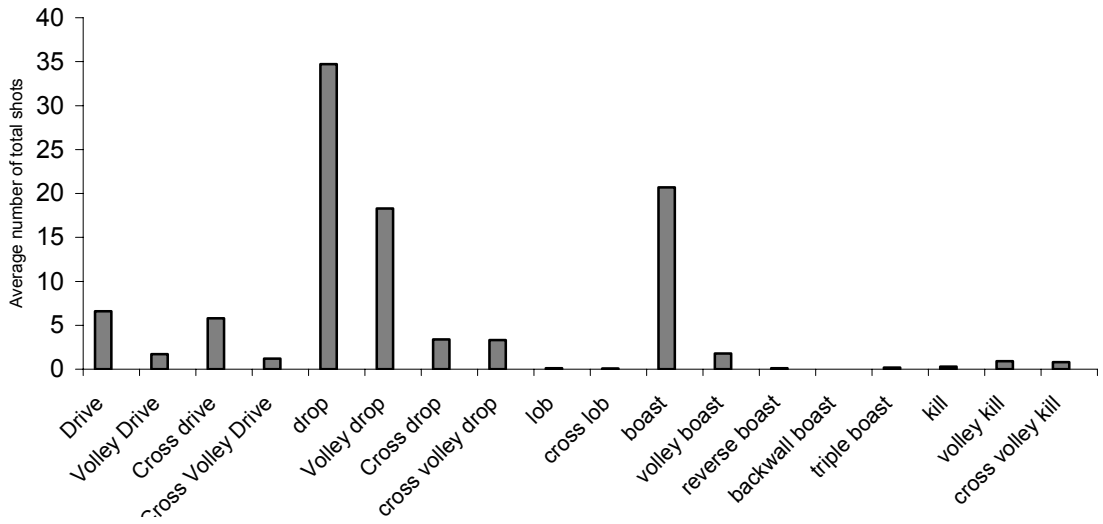

Figure 5. Type of shot that caused a perturbation when playing a squash match.

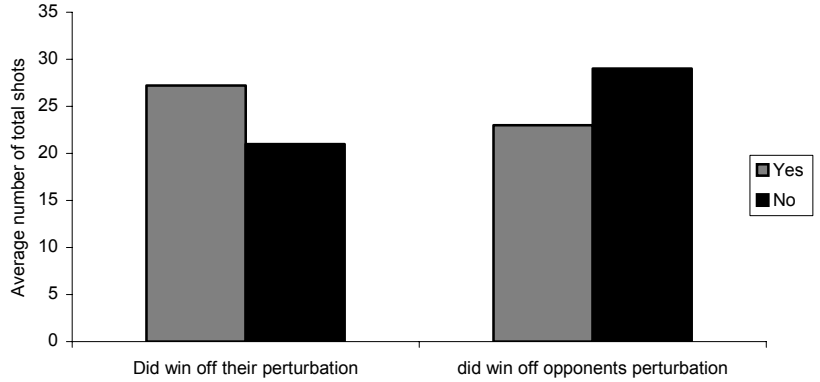

Figure 6. Graph to show whether a player was likely to win off perturbations when they caused them or whether they were more likely to win off them, when their opponent caused them.

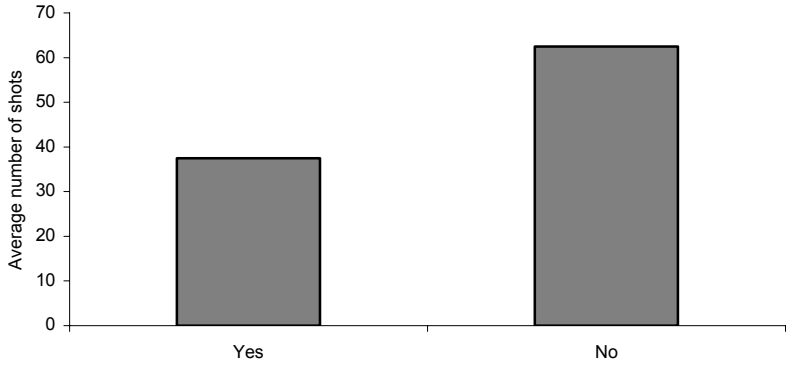

Figure 7. Graph to show whether games regain stability after a perturbation has taken place.

Hughes et al. (1998) also found that not all perturbations lead to critical incidents, and that some rallies do stabilise, they also concluded that not all critical incidents are preceded by a perturbation. This was also found in this investigation. The researcher stated that a perturbation only occurred if the player actually went for the shot. In some cases a player played a good shot, which the other player did not go for meaning a critical incident occurred without a prior perturbation. The researcher found that this normally happened in short rallies of up to four shots.

Perturbations were caused from all over the court, excluding the front four cells. Although the majority of perturbations were played from the backhand side close to the sidewall in cells 9 and 16. This may be because players are more consistent on the backhand side and it is here they feel most comfortable playing a perturbation, although players may also be under pressure here, and not in control of the 'T'. McGarry et al. (1998b) found that strong and weak shots are the most common cause for perturbations, when a player is under pressure in the back corners, they will play a short defensive shot, in order to allow themselves time to recover to the 'T', by creating a perturbation they are placing both their opponent and themselves under pressure as the stable rhythm of play has been disturbed. From the data gathered by England Squash it can be seen that overall winners and errors were played from the backhand side at the back of the court (Figure 4). These data are similar to those of profile by perturbations confirming that the backhand side is the more dominant side in a squash game. Winners were played from cell 1, 4, 9 and 12 and errors were played from 9, 12, 13 and 16 showing no similarities to the perturbation data gathered, after conducting a chi square analysis it was found that the two profiles were significantly different (χ^2 = 41.2;***P***<0.001). Another difference between the two profiles was players played a considerable number of perturbations from the four cells around the 'T', in comparison to both the winner and error profiles, indicating that perturbations are more often than not caused by opponents' weak shots. This indicates that perturbation profiles may have more similarities with the England Squash winner profiles compared to the error profiles. A significant difference between the two profiles was expected as when analysing disturbances in the system the process is being investigated, whereas the data gathered by England Squash is considering the end result, therefore this paper is investigating the process that causes the outcome.

Comparing the perturbation profile with the winner profile shows that the front four cells (1-4) are used to a greater extent when playing winners than when playing perturbations. This may be because players are winning from weak defensive shots, such as the boast, which is played to the front of the court. This is an important consideration as shots such as the boast were one of the main causes of perturbations, thus indicating players should be in an attacking position when attempting a perturbation. Cells 5-12 were used more often when creating perturbations confirming the use of perturbations in an attacking situation, as this is the area closest to the 'T'. The back four cells (13-16) were used equally in both profiles apart from cell 13, which was used considerably, more in the perturbation profile, probably due to the defensive style of play in the back corner. The fact that this row is used a

similar amount in each profile is interesting as it shows that winners have been created from these cells too. Although there was a significant difference between the two profiles when taking into consideration the fact that the perturbation profile is the process of getting to the winner profile some similarities begin to emerge between them.

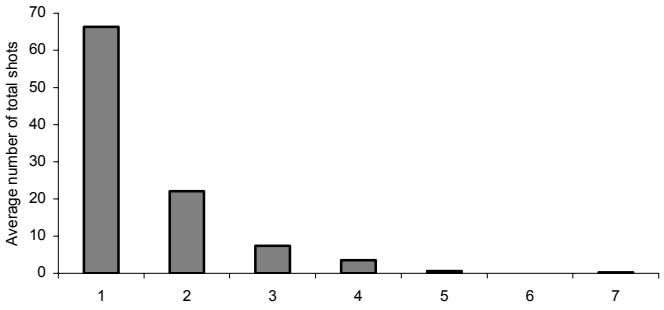

Figure 15: Graph to show how many time the rally regained stability

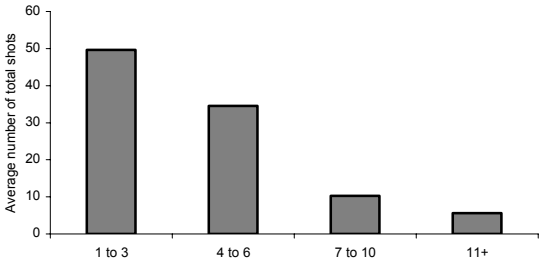

Figure 16: Graph to show after how many shots the graph regained stability.

2 3.4 Case Study

It was decided to carry out a case study to determine if different performance profiles are created when using perturbations compared to standard performance profiling, such as Hughes et al. (1985, 2000c). Two elite male players were selected for analysis, and England Squash performance analysts had already produced sufficient data for these players. The playing profiles were all tested for where players play perturbations from, where they have perturbations played against them, which shot they used to create perturbations and which shots were used against them, if they won off their own or their opponents perturbation, if the rally regained stability, how many times and after how many shots, as well as winner error distributions and shots that had caused these outcomes.

Subject 1 puts pressure on his opponent and plays an attacking style game. He creates his perturbations from the middle cells 9, 10, 11 and 12 as his opponent's are under pressure playing weak shots to the middle of the court. This subject's perturbation profile had the most shots played from the four cells around the 'T' compared to any other profile, emphasising the fact that he plays an attacking style game. His opponents only created winners from corner cells, 1, 13, 16 and perturbations from 9 and 13, again showing the constant pressure they are being placed under. The fact that perturbations are played from the backhand corner may be because defensive shots such as the drop and boast were the two shots that caused a perturbation against him. Considering that going short causes most perturbations, and the fact that his opposition are producing winners from cell 1 should be considered, although when Subject 1 creates a perturbation there is a good chance he will win off it. Subject 1's opponent uses similar shots to create perturbations and winners the drop, drive and boast, again indicating the lack of variation as well as the similarities between the perturbation and winner profiles. This player's profile was most likely to stabilise, with there being almost equal scores between yes and no. The profile will only stabilise once or twice in the rally and will stabilise quickly. Subject 1's perturbation profile and his opponents profile are significantly different (χ^2 = 36.5, 65.2;***P***<0.001), (χ^2 = 55.2, 65.8;***P***<0.001) to both England squash's winner and error profiles. When comparing Subject 1's perturbation profile to the overall male profile, there are more shots played from the four cells around the 'T' area, and there is a wider distributions of shots across the cells, with there being not as high percent in the main areas of the court, whereas Subject 1's opponent's profile is similar to that of the overall male perturbation profile.

3.3 Subject 1

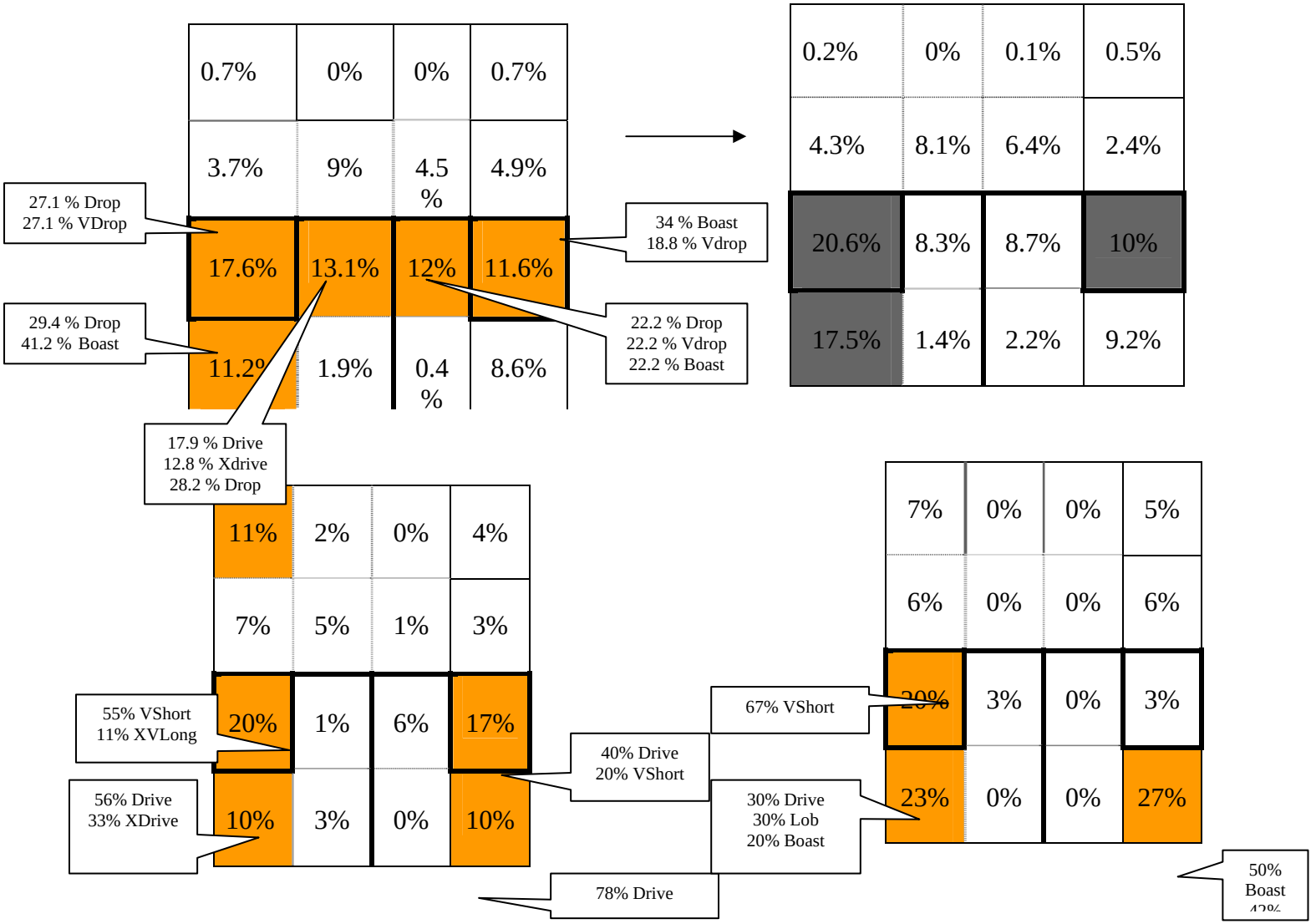

Figure 17: Performance profiles for subject 1, top is the comparison of where subject 1 play perturbations from to overall profile. Bottom left is England Squash's percent winner distribution, and right percent error distribution.

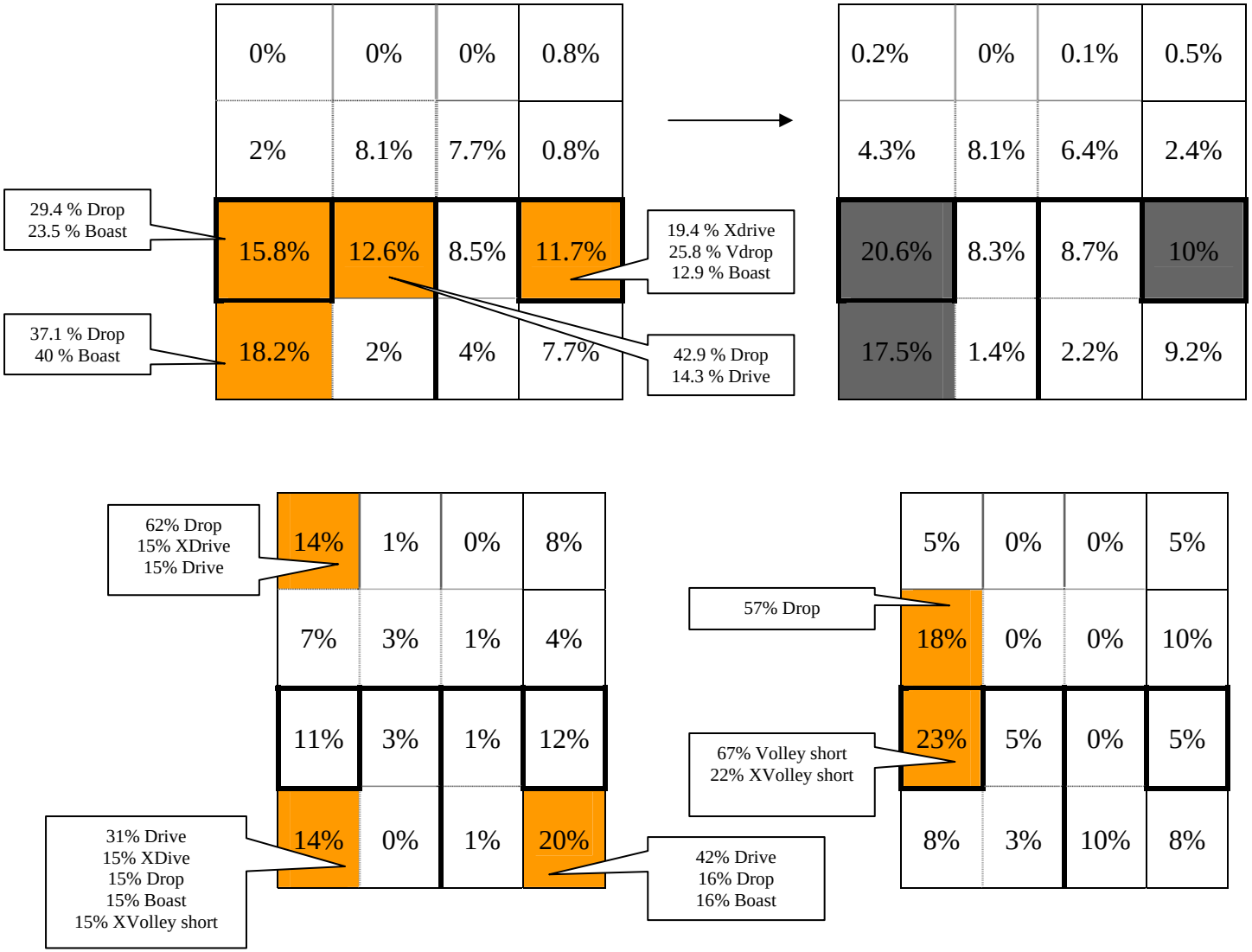

Figure 18: Performance profiles against subject 1, top is comparison between where subject 1 has perturbations played against them to overall profile. Bottom left is England Squash's percent winner distribution, and right percent error distribution for subject 1's opponents.

It was found that Subject 2 mainly created perturbations from the back two corners on both sides 9, 12, 13 and 16, showing a more defensive style of play which was more consistent with his error distribution, playing errors from cells 9, 12 and 13. When playing winners Subject 2 demonstrated a much more attacking style of play, playing winners from cells 8, 9 and 12 using a variety of shots including cross drive, drop, drive, volley short, cross volley short and cross volley long, although similar shots were also used for errors. When creating perturbations Subject 2 used the drop and boast showing less variety when creating disturbances in the system, this was the same as his opponents but they used the drop considerably more, this was consistent with winner and error distribution, where the drop was used noticeably more for both winners and errors. Subject 2 displayed similar means for winning off his own and opponent's perturbation, although his opponent is less likely to win off his perturbation, and there is a much higher chance his opponent will win of his own perturbation. Anthony Subject 2 profile is the least likely to stabilise, and will only stabilise once or twice, it also takes a while for his rally to stabilise. Rickett's perturbation profile was similar to the overall male profile, although using the four cells around the 'T' slightly less, confirming a more defensive style of playing. The volley drop was used a great deal from high percentage areas of the court, for Rickett's overall perturbation profile and the winner error profiles. Subject 2 opponent didn't use cell's 10 and 11 as much as other profiles when creating perturbations, otherwise a similar profile was found between the two profiles. Again there were similar shots between the perturbation profile and winner error profile for Subject 2's opponent, these shots being the drop and boast. Again it was found that this perturbation profile and his opponents profile are significantly different (χ^2 = 46.2, 35.7;***P***<0.001), (χ^2 = 40.3, 29.4;***P***<0.001) to both England squash's winner and error profiles.

Subject 1 and Subject 2 displayed different characteristics when playing, which have therefore produced very different profiles. Subject 1 played more perturbations from the middle of the court, showing a much more attacking style of play, and the fact he puts pressure on his opponents who play weak shots. Whereas Subject 2 played more perturbations from cells close to each sidewall, showing a more defensive style of play and being under more pressure from his opponents. Subject 1s profile although not significantly was similar to his winning profile, whereas Subject 2 profile was not similar to either winner or error but displayed characteristics of both. Although it would not be expected that players perturbation profiles are similar to either winner or error profiles it is interesting that Subject 1's profile is similar to his winner profile as it shows players use perturbations in different circumstances, although both players had a good chance of winning off perturbations they had caused, so although Subject 2 may have been more defensive he had the ability to follow his perturbations up.

McGarry and Perl (2004) stated that to analyse a squash contest as a dynamic system, it needs to be analysed by investigating whether the system can be detected as switching between periods of stability and instability from visual inspections. This was investigated in this research, and information was gathered confirming squash can be considered as a dynamic system. Rallies were found to switch between a rhythmical playing style and a non

rhythmical playing style through system disturbances analysed as perturbations. This was found to be reliably done, and opens up the opportunity to decide if sport as a whole can be described as a dynamic system. Systems with many dynamically interacting elements are capable of rich and varied patterns of behaviour which are clearly different from the behaviour of each component considered separately (Grehaigne, 1996). This has also been found in this investigation, as when performance profiles were created from perturbations, they were different to those created by England Squash who used winner error ratios. The fact that squash can be considered a dynamic system and produces different profiles when different components are considered, means notational analysis can be enhanced further and more in-depth profiles can be created.

4 Conclusions

It can be concluded that perturbations can be reliably identified in squash, meaning squash can be considered a dynamic system that transits from bouts of stability to instability. Evidence of multiple perturbations in a rally was also established. The three main shots that caused perturbations were the boast, drop and volley drop indicating going short causes most disturbances in the system. The backhand side at the back of the court was where most perturbations were played. After comparing the perturbation profile to the winner and error profiles significant differences were found between the two profiles, indicating perturbations provide further in-depth analysis of notational analysis of squash. After conducting a case study on two elite male players it was found that there were significant differences between the two players' profiles. Subject 1 used perturbations in a more attacking style whereas Subject 2 used perturbations in a defensive way showing variations in the use of perturbations.

3 4.1 Future Investigations

Hughes and Reed (2005) created a performance profile for Arsenal when winning and losing, within this investigation all games were grouped together, and didn't take into consideration if players played differently when winning and losing like McGarry and Franks (1994b) suggested. If there had been more time then profiles should be created when players are winning and losing using perturbations. McGarry and Franks, (1994) found previous performance could be used to predict next matches response, this should be investigated to see if perturbations can be used to predict future performance. Another factor that would be interesting to investigate when examining perturbations would be to analyses perturbations when a player has played a weak defensive shot to cause a perturbation, and when a player creates a perturbation in an attacking situation, and if the shots and position cells changes when a player is in different situations.

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