Determining unstable game states to aid the identification of perturbations in football

Jongwon Kim[1], Nic James[1], Nimai Parmar[1], Besim Ali[2] & Goran Vučković[3]

[1]*London Sport Institute, Faculty of Science & Technology, Middlesex University, London, UK*
[2]*Fulham Football Club, Motspur park, Surrey, UK*
[3]*Faculty of Sport, University of Ljubljana, Ljubljana, Slovenia*

Abstract

Mackenzie and Cushion (2013) suggested alternative approaches to the reductionist method for analysing football were needed to better understand factors typically not considered e.g. off the ball runs by teammates. The dynamical systems approach, where the complex relationships between players is emphasised, predicts that goal scoring opportunities are preceded by instability in the balance between the two teams' behaviours (Frencken, de Poel, Visscher & Lemmink, 2012). The aim was to create operational definitions for determining unstable game states to facilitate the identification of perturbations i.e. the causes of instability. Validity tests involving 4 English Premier League (EPL) football coaches and 2 performance analysts and subsequent reliability tests established 5 unstable game states; penalty box possession, counter attack, ratio of attacking to defending players, successful cross and successful shot. Eighteen EPL matches were analysed to present exemplar statistics for three teams of different standard (based on final league position) suggesting that teams create unstable situations differently, likely due to individual player characteristics, with home advantage and opposition strength effects, suggesting this may be a component of what constitutes a performance indicator for a team (Hughes & Bartlett, 2002). Future studies need to consider individual player actions that create instability as well as provide objective measures that substantiate findings.

Key words: perturbations, unstable situations, game states, football

1. Introduction

Mackenzie and Cushion (2013) suggested that numerous research papers have contributed to the development of sport's performance analysis although many have been criticised for both methodical and conceptual concerns (see also Hewitt, Greenham, & Norton, 2016). For example, James (2006) suggested that some notational analysis studies lacked precise operational definitions which are likely to make some event codes incorrect. Mackenzie and Cushion (2013) found that 79% of papers did not fully define variables and 31% provided no

operational definitions, the majority of performance analysis research had adopted a reductionist approach which considers only selected events such as number of shots or pass success rates for analysis and that variables had been measured because of availability rather than to develop a deeper understanding of performance. Football is a complex sport involving many players and different situations and it is not plausible that a reduced set of action variable can consistently predict the game result with the exception of goals scored, which is both obvious and uninformative. However, common findings such as winning teams created significantly more shots, higher pass accuracy or ball possession compared to losing teams are pervasive in the extant literature (e.g. Hook & Hughes, 2001; Stanhope, 2001; Jones et al., 2004; Hughes & Churchill, 2005; Hughes & Franks, 2005; Lago-Peñas et al., 2010; Lago-Peñas et al., 2011). James (2009) suggested the obvious problem associated with this type of study was that simply analysing outcome measures (performance indicators, Hughes & Bartlett, 2002) cannot provide meaningful information for improvement of performance without an understanding of the processes undertaken to achieve these outcomes. Furthermore, the way in which these processes take place are likely to depend on the moment of the match i.e. established attack, offensive transition or set pieces (Hewitt et al., 2016).

The dynamical systems perspective has been suggested as a different methodological approach to analysing sports performance where the whole performance is considered. This approach considers the behaviours of all participants, as opposed to selected events, and how their interactions determine game outcomes (McGarry et al., 2002). Intuitively, this approach seems well suited to the analysis of football, the anthesis of the reductionist approach, although squash was the first sport to be analysed. McGarry et al. (1999) showed 60 rallies from the 1988 Men's Canadian Open Squash Championship to six expert and six non-expert squash coaches and asked them to identify when rallies changed from a stable situation, defined as neither player having an advantage over the other, to an unstable one where one player had an advantage. The coaches could reliably identify the shot which occurred between these two hypothesised game states although occasionally either one of two consecutive shots were identified. The authors suggested that this transition point could contain a perturbation, described "as an event which caused the change in game state", in this case 85% were identified as strong or weak shots.

The idea that sporting events could display both unstable and stable situations is intuitively appealing as it seems sensible that when a team has a goal scoring opportunity the defending team would be in an unfavourable situation and hence attempt to rectify the situation

i.e. goal scoring opportunities are preceded by instability in the balance of the team's behaviours (Frencken, de Poel, Visscher & Lemmink, 2012). The concept of these two game states is therefore pretty simple to understand and logically valid. However, the term perturbation, the theoretical precursor, or cause, of the unstable situation is less obvious. McGarry et al. (1999) did not attempt to determine what a perturbation was, or could be, rather they presented the case for stability and its antithesis, instability. Roddy et al. (2014) investigated perturbations during critical incidents in squash i.e. the last three shots played in rallies that were won. Perturbations were deemed to have occurred if the rally loser was out of position when playing the shot immediately prior to the opponent playing a winner. This is different to McGarry et al.'s (1999) view, who suggested that perturbations could be "smoothed out" i.e. stability in the rally maybe regained after a perturbation had caused instability.

The relatively recent advent of player and ball tracking in football has allowed researchers to utilise a dynamical systems approach to better understand the complex relationships between players. For example, Vilar, Araujo, Davids and Bar-Yam (2013) assessed defensive stability and attacking opportunities in relation to ball and player location changes. Using one match played in the 2010 EPL season the net team numerical advantage was calculated frame by frame using Shannon's entropy as a measure of uncertainty. Similar studies in football have considered, for example, the positional centroid of a team as (a precursor to critical events; Frencken, et al., 2012) or (a measure of tactical behaviour; Sampaio & Maçãs, 2012) and the speed of contraction or expansion of the team surface area (to measure team organisation; Moura et al. 2013). These types of study have been reviewed by Memmert, Lemmink and Sampaio (2017).

James et al. (2012) analysed perturbation attempts in football, events which either caused (or were part of) a change in game state (perturbation) or didn't (not a perturbation). They described these actions as ones whose purpose was to create instability i.e. a goal scoring opportunity. They further defined a stable situation as when neither team had an imminent goal scoring opportunity. An attempt to create a goal scoring opportunity e.g. a pass into the penalty box, would be successful if an attacker was then in a position to score a goal (an unstable situation). This could be described as a perturbation although the explanation for the perturbation would not be simply the pass, it would also include the ball receiver as well as potentially other factors such as defenders out of position etc. Using the same example, if the attacker was unable to kick the ball e.g. a defender intercepted the ball, the situation would remain stable and therefore the perturbation attempt deemed unsuccessful i.e. there was no

perturbation. Eight matches resulted in an average of 78 perturbation attempts per match with passes accounting for the highest frequency (home=63.4%, away=56.2%) with the home team attempting to create perturbations more frequently when drawing (1 attempt every 1.71 minutes) than winning (2.08 minutes) or losing (2.20 minutes).

Link, Lang, and Seidenschwarz (2016) used player and ball tracking data to quantitively determined the probability of a goal being scored, named "dangerousity". Using the position of the player in possession of the ball, ball speed, defensive pressure and defensive organisation the authors effectively provided a measure which could be useful in the classification of an unstable situation. They performed a validity test using three semi-professional football coaches who rated 100 game situations in terms of danger (1 little danger to 5 very dangerous). The degree of agreement between coaches, and between coaches and the algorithm, suggested that observers can evaluate the extent to which a goal scoring event could occur and the basis of this is measurable using player and ball positions.

The aim of this paper was, therefore, to define unstable game states to aid the future identification of perturbations in football. Whilst previous papers have attempted to identify perturbations, there were no operational definitions for stability, instability or perturbations, with consequent subjectivity for determining these events. If unstable, and therefore stable situations, can be reliably differentiated, then the identification of perturbations is more likely since match data can be reduced to only include relevant periods. This methodology may also aid future quantitative studies using player and ball positions to determine goal scoring threat.

2. Methods

2.1 Sample

Three English Premier League teams were selected by opportunity sampling from commercially broadcast footage of the 2015-16 season. The first 14, and final 5 weeks of the season were excluded because league positions can be unrepresentative of playing standard at the start of the season and potentially affect match performance at the end of the season. Each selected team played 6 different opponents, balanced for quality based on league position at the time the match was played (1-6=top, 7-14=middle, 15-20=bottom) and venue (home and away).

2.2 Creating valid Operational Definitions for Unstable Situations

James et al. (2012) defined an unstable situation as where one team had a potential goal scoring opportunity. This was used as a basis for operationally defining different situations that the researchers felt fulfilled this criterion. Subsequently, after watching all situations, rather than cherry picking just goal scoring situations, from the start of possession, five mutually exclusive situations were identified that were relevant to creating a goal scoring opportunity i.e. unstable situation. Whilst more than one of these situations could occur in a single possession only the first one that occurred was used to classify the situation. Operational definitions were then created for each situation and their validity assessed in the following test.

Thirty video clips were edited such that some contained situations deemed unstable by the researchers (3 examples of each of the 5 situations) and some not deemed unstable (n=15). The clips were shown to 4 professional football coaches and 2 performance analysts. All coaches and analysts had more than 5 years coaching experience and were currently employed at an English Premier League club. They were briefly instructed as to what the researchers considered to be an unstable situation i.e. a potential goal scoring opportunity and then independently viewed each clip, with the opportunity to watch on more than one occasion, before deciding whether the situation was stable, unstable or they were not able to decide. They were also asked to explain the reasons for their decisions. At the completion of this process, a discussion between the first researcher and the coach/analyst was undertaken with a view to clarifying differences of opinion such that the five operational definitions of different 'unstable situations' could be modified if necessary so that all definitions met the approval of all coaches, analysts and researchers. The final definitions were:-

- Penalty Box Possession **(PBP)**

  "Having possession of the ball inside the penalty area with the possibility to shoot, pass or dribble"

This category of unstable situation was a consequence of the ball location, namely that the close proximity of the goal meant that a goal threat was highly likely. This situation arose when a played dribbled into the box, received a pass or regained the ball from an opponent. Whilst this situation could vary in terms of goal threat, a scoring opportunity was either immediate or imminent unless the defending team were in position to prevent the player in possession of the ball from doing anything. This definition was modified to include the caveat that opposition

defenders could prevent a goal scoring opportunity when a player had possession inside the penalty box after all coaches disagreed that one of the PBP video clips was unstable because the defenders had prevented the player in possession any opportunity to do anything with the ball. All agreed that the other two PBP clips were unstable situations.

- Counter Attack **(CA)**

> "When a team regained possession and quickly moved the ball forwards, resulting in the opponent's defenders having to quickly reorganise from an un-organised position"

This category of unstable situation was a consequence of the situation, namely that a sudden change in circumstances has put the defending team in a critical moment. Counter attacks are a well-known feature of football although a precise definition is less available (sometimes referred to as transitions; Hewitt, Greenham, & Norton, 2016). This definition did not specify where on the pitch the ball was regained as different areas including both halves were often considered in this category. The consistent aspects in counter attacks were the speed at which the ball was played forwards toward goal and the need for defenders to run fast to try to get into good positions (reorganise). On the three video clips shown to coaches and analysts there were 17 agreements (out of the 18 responses).

- Ratio of Attacking to Defending players **(RAD)**

> "The attacking team had a greater or equal number of players, compared to the defending team, between the ball and the opponent's goal line as long as the number of active defenders was less than 5"

This category of unstable situation was also a consequence of the situation i.e. a sudden change in circumstances has put the defending team in a critical moment e.g. a successful pass through a defensive line (Link, Lang & Seidenschwarz, 2016). When classifying opposition players as defenders it is usual to only consider players behind, or in line, with the ball since the other players are effectively unable to influence the attack. These defending players are under the most pressure when their numbers are low because of the space they need to defend. Hence, we determined that in situations where less than 5 defending players were trying to defend against the same or more attackers the situation was deemed unstable. The coaches and analysts made 17 agreements (out of the 18 responses) on these video clips and verbally agreed this classification.

- Successful Cross **(SC)**

> "A long pass from a wide area into, or close to, the penalty box, where a) the first touch by a team mate had a chance of scoring a goal, b) the team mate failed to touch the ball even though the cross provided the scoring opportunity or c) the cross resulted in the defender undertaking a high risk defensive action playing the ball towards his own goal"

This category of unstable situation was a consequence of an action i.e. a stable situation could be changed to unstable as a consequence of a good pass even though the defensive formation sometimes remained well organised and seemingly stable. Only a successful cross could achieve instability as a cross that was headed away by a defender, saved by the goalkeeper or did not have any chance of being met by an attacker could not induce any problems for the defending team. Sometimes the receiving player did not make contact with the ball e.g. he mistimed his jump, but the cross was still deemed successful if the failure was deemed to be the receiver fault rather than the passing player. The third situation where a defender undertook a high-risk defensive action i.e. playing the ball towards his own goal, the classic own goal situation, accounted for the pressure placed on the defending team even though they could touch the ball before the attacking team. The coaches and analysts made 12 agreements (out of the 18 responses) on these video clips. Two coaches agreed with the operational definition but considered that when the defensive players were well organised they (the players) considered the situation stable. They explained that, in their opinion, some teams preferred to allow crosses, rather than other types of play, because of their strength in defending crosses. They considered this to be different for different teams but responded to the video clips shown using their logic (defensive perspective) as opposed to our logic (offensive threat). On this basis the operational definitions were unchanged as this opinion was not shared by the other participants or researchers.

- Successful Shot **(SS)**

> "A shot toward opposition's goal having a possibility of scoring a goal regardless of result (on target/off target/blocked)"

This category was a consequence of a shot i.e. a stable situation could be changed to unstable as a consequence of a good shot even though the defensive formation was well organised and seemingly stable. Occasionally, a player may decide to shoot, either when there are no other

options or because he thinks there is a small chance of scoring. The coaches and analysts made 15 agreements (out of the 18 responses) on these video clips and verbally agreed this classification. Some coaches considered the defence had been successful in allowing this type of shot because of the very low chance of success.

2.3 Procedure

Matches were viewed on SportsCode Elite v10.3.36 and Apple Movist v1.3.6 to facilitate coding using full screen, pause, replay and slow motion. Each unstable situation was notated for team, time, unstable category (PBP, CA, RAD, SC, SS), outcome (no shot, shot on target, shot off target, goal), venue (home, away) and opponent quality (against top, middle, bottom teams).

On some occasions a single team possession could include more than one unstable situation category e.g. a counter attack could result in a penalty box possession. If the unstable situation did not revert back to stability the classification of the instability was always the first one that occurred. However, if the situation did revert back to stability the two (or more) unstable situations were recorded as separate events. This methodical procedure allowed the identification of the time at which an unstable situation arose (t_u, Figure 1) which, in most situations would be preceded by a stable situation, during which time the literature suggested a perturbation occurred i.e. to create the unstable situation.

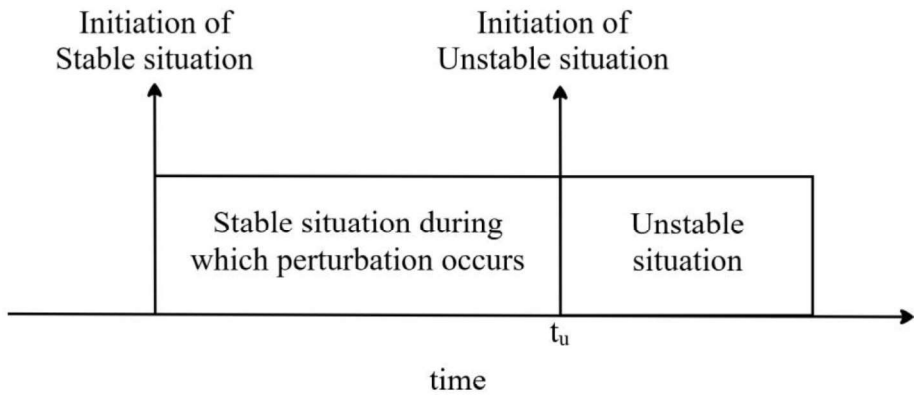

Figure 1. The timeline for an unstable situation arising from stability

2.4 Reliability

Reliability tests were performed at the level of data analysis i.e. to determine whether unstable situations (n=5) and outcomes (n=4) were reliably categorised using intra- and inter-observer tests (James, Taylor, & Stanley, 2007). Three randomly selected matches were re-coded by the

researcher (over 4 weeks after the initial coding to negate memory effects) and an independent football expert (15 years' experience) who was trained on the operational definitions but not used for the validity assessment.

Unstable situations (PBP, CA, RAD, SC, SS) had high Kappa values for inter- (0.93, n=162 comparisons) and intra-operator (0.98, n=161) tests. Discrepancies tended to occur when an analyst missed an event (n=7 and n=2 respectively) rather than incorrectly classifying events (n=2 and n=0 respectively). Also, outcomes (no shot, shot off target, shot on target, goal) had high Kappa values for inter- (0.95, n=79 comparisons) and intra- (0.95, n=80) due to an analyst missing an event (n=2 and n=2 respectively).

2.5 Statistical Analysis

Data were analysed in IBM SPSS (v25, IBM Corp) to determine non-normality and outliers ensuing that median and interquartile range values were presented for unstable situations and outcomes. A Kruskal-Wallis H test determined differences for matches against different quality teams (top, middle, bottom) and a Mann-Whitney U for venue (home and away).

3. Results

Teams created a median of 26.5 unstable situations (IQR=15.5) per match, resulting in 13.5 (IQR=8.0) shots and 1 goal (IQR=2.0). The three teams created unstable situations in a similar pattern (chi-square=11.6, df=8, p=0.18, Cramer's V=0.11; Figure 2).

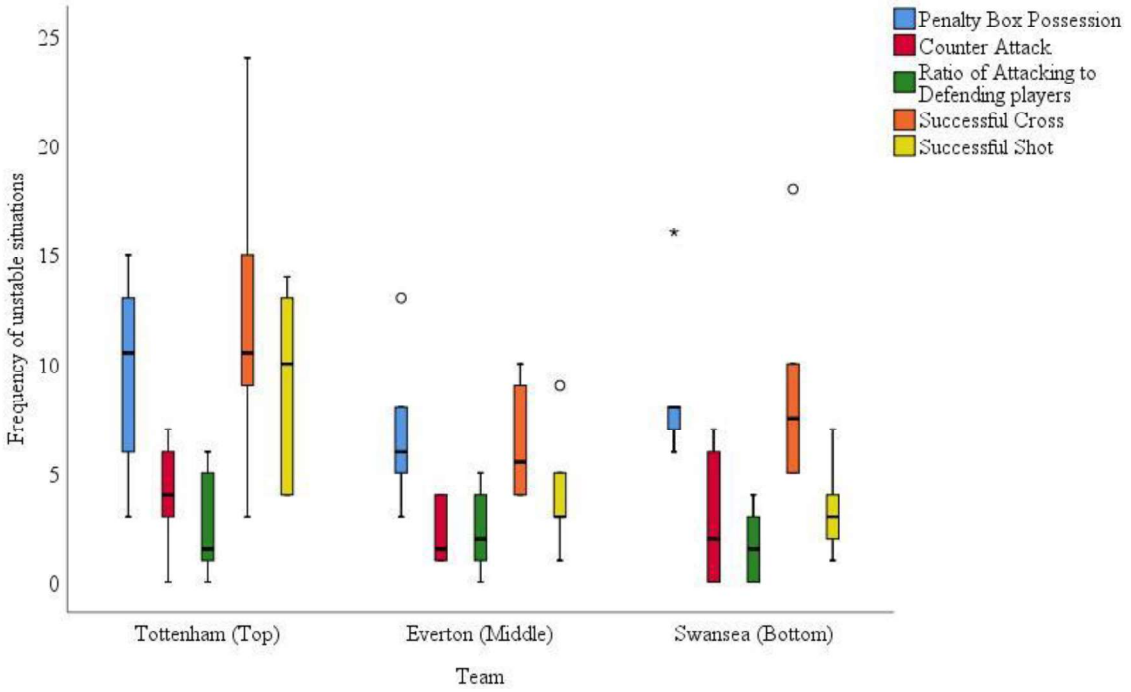

Figure 2. The frequency of unstable situations per match by three different quality teams

Home teams (Median=30.5, IQR=15.3) created more unstable situations (Mann-Whitney U=88.5, p<.05) than away teams (Median=21.5, IQR=13.0; Figure 3). Teams also created less unstable situations (Chi square=7.1, df=2, p<.05) playing against top teams (Median=20.0, IQR=8.8) than when playing against middle teams (Median=28.5, IQR=16.0) or bottom teams (Median=30.5, IQR=8.5; Figure 4).

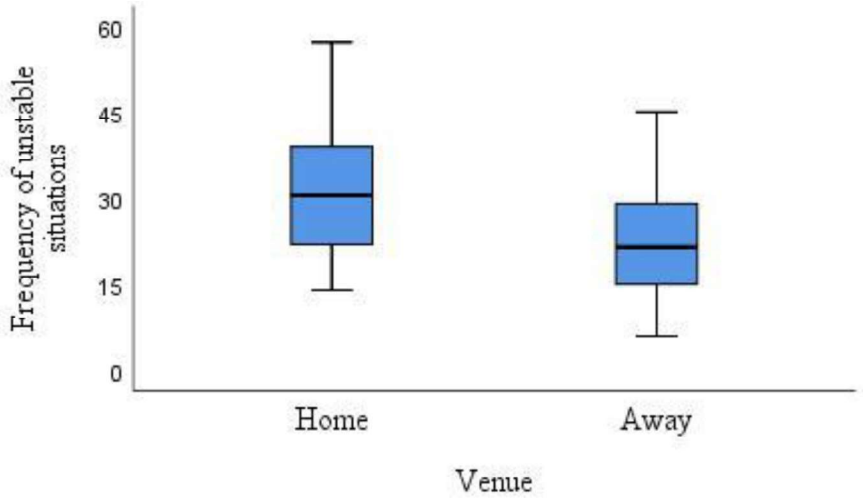

Figure 3. The frequency of unstable situations per match by venue

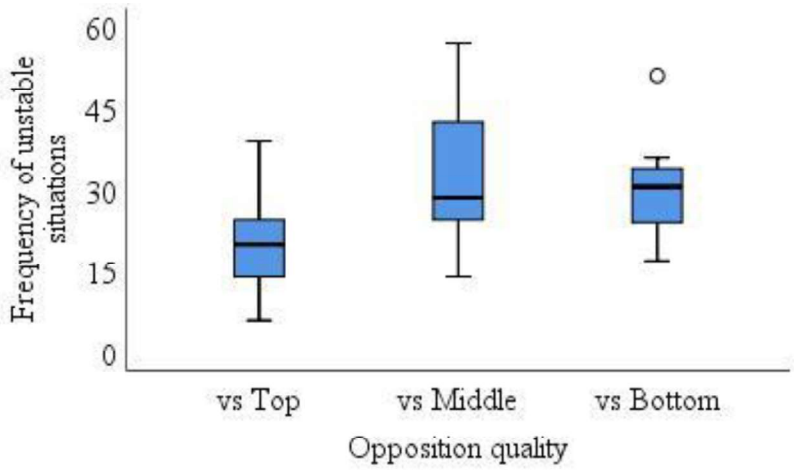

Figure 4. The frequency of unstable situations per match by opponent team quality

4. Discussion

An alternative approach to the reductionist method for analysing football has been proposed (Mackenzie & Cushion, 2013) with the dynamical systems approach favoured by some (e.g. Vilar et al, 2013). These studies have tended to focus on team formations, interpersonal distances and passing areas (Memmert, Lemmink & Sampaio, 2017) although recently player and ball locations have been used to quantify the likelihood of a goal being scored (Link, Lang & Seidenschwarz, 2016) and whether team centroids relate to instability (Frencken et al., 2012). However, very small differences in player and ball positions, ball control etc. can have dramatic influences on whether an outcome is successful or not. This study attempted to classify goal scoring opportunities (James et al., 2012) according to location (penalty box possession), situation (counter attack, ratio of attacking to defending player) and action (successful cross, successful shot). These situations were identified following a rigorous process of defining, and subsequently amending following a validity test, operational definitions that distinguished the initial starting point of an unstable situation. Numerical measures of "dangerousity" were not computed but this would be an interesting next step as logically the advent of an unstable situation should correspond to a big increase in "dangerousity". Link, Lang and Seidenschwarz (2016) found this to be case e.g. for a successful pass through a defensive line, suggested to concur with the disruption of the balance between the defending and attacking teams Cf. perturbation, in concordance with the theory of dynamic systems (James et al., 2012).

This study provided valid definitions of unstable situations which can help researchers identify the critical periods of a match during which perturbations occur. The explanation for

perturbations occurring in football is likely to be more complex than sports such as squash which only involve two players (McGarry et al., 1999). For example, whilst a successful pass through a defensive line was considered a perturbation (Link, Lang & Seidenschwarz, 2016) the circumstances allowing the successful pass inevitably included off the ball runs by teammates and potentially incorrect positioning by some opposition players. These highly significant aspects of play tend to be overlooked by traditional on the ball analyses. The identification of unstable situations, therefore, has the potential of simplifying the analysis of football significantly, as researchers can focus on the critical moments rather than analysing the whole match. From a coaching perspective this is obvious, coaches want to know how teams create imbalances, as well as how to prevent them (personal comment by EPL coach during validity study).

The exemplar analyses of three teams of different standard (based on final league position) suggested that different teams will create unstable situations differently, due to the quality of the team, a by-product of the qualities of individual players. This, between team variability, is to be expected since differences in team tactics, to exploit the strengths of the best players, will inevitably be translated into patterns of perturbation formation, knowledge of which would logically be of great value to coaches. The frequency of unstable situations in this study also supported home advantage and opposition strength effects, hence increasing the validity of this measure as a performance indicator (Hughes & Bartlett, 2002).

5. Conclusion

Traditional analyses of football matches that consider isolated performance variables over full matches cannot reveal all the relevant factors that explain successful performance. However, the complexity involved when 22 players interact, particularly when very small differences e.g. control or lack of control of the ball, affect the outcome massively, is profound. Techniques to simplify and reduce an analysis are therefore essential if meaningful, and useful to coaches, results are to be achieved. Differentiating the moments of a match (Hewitt, Greenham, & Norton, 2016) and significant periods of play e.g. perturbations and unstable situations, are therefore paramount. This study has presented reliable and valid definitions of unstable situations in football, the significant periods of play which include or are preceded by perturbations. Future studies need to present a conceptual framework for analysing individual

player, and playing position specific, actions that create instability along with objective measures of player and ball positions that substantiate the findings.

6. References

Frencken, W., de Poel, H., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences,* 30(12), 1207-1213.

Hewitt, A., Greenham, G., & Norton, K. (2016). Game style in soccer: what is it and can we quantify it? *International Journal of Performance Analysis in Sport*, 16(1), 355-372.

Hughes, M.D., & Bartlett, R.M. (2002). The use of performance indicators in performance analysis. *Journal of Sports Sciences*, 20(10), 739-754.

Hughes, M.D., & Churchill, S. (2005). Attacking profiles of successful and unsuccessful teams in Copa America 2001. In T. Reilly, J. Cabri, & D. Araujo (Eds.), *Science and Football V* (pp. 219-224). Abingdon, UK: Routledge.

Hughes, M., & Franks, I. (2005). Analysis of passing sequences, shots and goals in soccer. *Journal of Sports Sciences*, 23(5), 509-514.

Hook, C., & Hughes, M. (2001). Patterns of Play Leading to Shots in Euro 2000. In M. Hughes, & I. Franks (Eds.), *Pass.Com*, Cardiff: Centre for Performance Analysis, UWIC, 295-302.

James, N. (2006). Notational analysis in soccer: Past, present and future. *International Journal of Performance Analysis of Sport*, 6(2), 67-81.

James, N. (2009). Performance analysis of golf: Reflections on the past and a vision of the future. *International Journal of Performance Analysis in Sport*, 9(2), 188-209.

James, N., Rees, G.D., Griffin, E., Barter, P., Taylor, J., Heath, L., & Vuckovic, G. (2012). Analysing soccer using perturbation attempts. *Journal of Human Sport & Exercise,* 7(2), 413-420.

James, N., Taylor, J. B., & Stanley, S. (2007). Reliability procedures for categorical data in performance analysis. *International Journal of Performance Analysis in Sport*, 7(1), 1-11.

Jones, P.D., James, N., & Mellalieu, S.D. (2004). Possession as a performance indicator in soccer. *International Journal of Performance Analysis of Sport*, 4(1), 98-102.

Lago-Peñas, C., Lago-Ballesteros, J., Dellal, A., & Gomez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *International Journal of Sports Science and Medicine*, 9(2), 288-293.

Lago-Peñas, C., Lago-Ballesteros, J., & Rey, E. (2011). Differences in Performance Indicators between Winning and Losing teams in the UEFA Champions League. *Journal of Human Kinetics*, 27(1), 135-146.

Link, D., Lang, S., & Seidenschwarz, P. (2016). Real Time Quantification of Dangerousity in Football Using Spatiotemporal Tracking Data. *PLoS ONE*, 11(12), e0168768, doi:10.1371/journal.pone.0168768

Mackenzie, R., & Cushion, C. (2013). Performance analysis in football: A critical review and implications for future research. *Journal of Sport Sciences*, 31(6), 639-676.

McGarry, T., Anderson, D.I., Wallace, A., Hughes, M.D., & Franks, I.M. (2002). Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences,* 20(10), 771-781.

McGarry, T., Khan, M.A., & Franks, I.M. (1999). On the presence and absence of behavioural traits in sport: An example from championship squash match-play. *Journal of Sports Sciences,* 17(4), 297-311.

Memmert, D., Lemmink, K.A.P.M., & Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Medicine*, 47(1), 1-10.

Moura, F.A., Martins, L.E.B., Anido, R.O., Ruffino, P.R.C., Barros, R.M.L., & Cunha, S.A. (2013). A spectral analysis of team dynamics and tactics in Brazilian football. *Journal of Sports Sciences,* 31(14), 1568-1577.

Roddy, R., Lamb, K., & Worsfold, P. (2014). The importance of perturbations in elite squash: An analysis of their ability to successfully predict rally outcome. *International Journal of Performance Analysis in Sport,* 14(3), 652-679.

Sampaio, J., & Maçãs, V. (2012). Measuring tactical behaviour of football. *International Journal of Sports Medicine*, 33, 395-401.

Stanhope, J. (2001). An Investigation into Possession with Respect to Time, in the Soccer World Cup 1994. *(Edited by Hughes, M)*: *Notational Analysis of Sport III. Cardiff: Centre for Performance Analysis,* UWIC, 155-162.

Vilar, L., Araűjo, D., Davids, K., & Bar-Yam, Y. (2013). Science of winning soccer: Emergent pattern-forming dynamics in association football. *Journal of Systems Science and Complexity*, 26(1), 73-84.