SECTION II

Measurement and evaluation in sports performance analysis
TACTICAL PERFORMANCE ANALYSIS IN INVASION GAMES

Perspectives from a dynamic system approach with examples from soccer

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Summary

Performance analysis in invasion games like soccer, basketball, handball, rugby and field hockey requires objective recording and examination of behavioural events of one or more players during training or competition. The primary goal of performance analysis is to provide information to coaches and players about player and/or team performance in order to plan subsequent practices to improve performance or to support preparation for the next match. Performance analysis is most often used to create a permanent record of actions of players within a match through hand-based or computerized systems, often using video technology. Sophisticated data sets offer opportunities for analysing spatio-temporal patterns and network structures. However, these analyses have certain limitations, especially from a tactical point of view. For example, spatial information of the actions of players, if present at all, lacks accuracy and, due to a single camera viewpoint, only on-the-ball actions of individual players are monitored systematically.

Technological innovations, such as tracking based on synchronized multiple video cameras and Global Positioning System technology, have led to new possibilities for match and training analysis in ball team sports. Positional player data (up to 1000 Hz) are collected in the context of different ball team sports, such as soccer for example. These data are typically used to calculate distance, speed and acceleration/deceleration profiles of individual players. These analyses do not capture the game dynamics and complexity of a soccer match, however, and new approaches of the game are required for tactical analyses.

Dynamical systems theory offers a framework for analysing player and team interactions and its analytical tools and methods are ideal for coping with high spatial-temporal resolution data. For example, on an individual level it allows for analysis of symmetry-breaking processes in player dyads, whereas on the team level offensive and defensive spaces or other
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tactical performance in games like soccer, basketball, handball, rugby and field hockey addresses the quality of actions of individual players or teams in space and time during training or match-play. In other words, to analyse tactical performance, information is required on 'what', 'how', 'where' and 'when'. Tactical behaviour is constrained by personal characteristics, such as physical and technical capacities of players, task details, such as number of players, pitch size dimensions or scoring on two goals in small-sided games, and situational variables, such as home versus away matches. The primary goal of tactical performance analysis is to provide information to coaches and players about player and/or team performance in order to plan subsequent practices to improve performance or to support preparation for the next match (Maslovat and Franks, 2008; Carling et al., 2009).

Notational analyses have dominated the scientific literature on tactical performance analyses over the last couple of decades (Hughes and Franks, 2004). Notational analysis is a method to create a permanent record of on-the-ball actions of players ('what' and 'how') within a game through hand-based or computerized systems, often nowadays using video technology. Basic systems simply classify the type of actions of the players. More sophisticated systems gather information on global position of the actions on the field ('where') and sequence/time of actions ('when'), which allows spatial and temporal analysis. Other systems have tried to define actions (e.g. passes, in terms of success or unsuccess or to rate the quality on a three or five-point scale). Next to real-time or day-after use of a single training session or match, notational systems can be used to analyse a series of matches during tournaments such as the European or World Championships and continental competitions such as the Champions League or Euro league, as well as national competitions. Large amounts of sophisticated notational data open up new approaches. Temporal (T-pattern) analysis can find (hidden) patterns of play using sequences of actions in relation to success, for example, winning or losing a game, creating goal scoring opportunities or playing level (Borrie et al., 2002). Social network approaches or neural network approaches can shed light on how interpersonal interactions lead to coordinated patterns of plays that are related to successful performance outcomes (Duch et al., 2010; Passos et al., 2011). These approaches seem promising in expanding knowledge on tactical performance.

Although these notational systems have improved over time, they have certain limitations, especially from a tactical point of view (Lemmink and Frencken, 2009). First, due to a single camera viewpoint, only on-the-ball actions are monitored systematically. However, it can be argued that the behaviour of an individual player during training or a match is brought about by interactions with teammates and opponents. Second, spatial and temporal information of notational systems lack sufficient accuracy to analyse in-depth tactical performance.

In recent years, (semi)-automatic tracking methods based on video or GPS-like technologies have been developed to collect spatio-temporal information (i.e. positional data over time) from all players during training or matches (Carling et al., 2008, 2009). These methods provide a new means to calculate players’ physical demands (i.e. distance covered, speed profiles, acceleration/deceleration patterns and directional changes). Once high-quality ball positional data become available, it also opens up new ways of analysing tactical performance during training...
or matches. The main advantage of these new methods is that accurate spatio-temporal information (‘where and when’) of all players is available. Configurations of the players on the field reflect the interaction between the players and the ball. As play progresses, spatio-temporal patterns emerge from the dynamics of the game.

The dynamical systems approach has shown to be useful for understanding spatio-temporal patterns in individual and team sports (Frencken and Lemmink, 2008; Gréhaigne et al., 1997; McGarry et al., 1999, 2002; McGarry, 2005; Palut and Zanone, 2005; Reed and Hughes, 2006). The core of this theory is that the behaviour of a system is brought about by interactions of many subsystems. The dependent variable, or collective variable, describes the state of the system at any instant. Finding the collective variables that capture the dynamics of a system is an important scientific challenge.

Ball team sports like basketball, handball, field hockey, rugby or soccer are complex, primarily due to the invasive nature and the number of players. Gréhaigne et al. (1997) and McGarry et al. (2002) proposed that interactions between soccer players give rise to team behaviour and may be described as a dynamical system. As suggested earlier, positional information of players over time reflects interactions between players. So, positional data of players have the potential to describe the dynamics of training and matches.

Analyses have primarily focused on collective variables in discrete 1 v 1 training or match situations. Araújo et al. (2004) analysed 1 v 1 situations in basketball. They calculated the median point of the distance between the players to the goal area and the interpersonal distance between attacker and defender, with the former being the collective variable and the latter being a control parameter. Results showed that the attacker fluctuates the direction of attack in front of the defender and the defender countermoves in order to maintain stability. From these data, Araújo et al. (2004) concluded that features of dynamical systems were established in a 1 v 1 attacker–defender dyad in basketball. Recently, this finding was confirmed in studies by Bourbousson et al. (2010a), from intra- and inter-couplings among player dyads in basketball, and Passos et al. (2006) and Passos et al. (2008), using interpersonal distance and relative velocity in attacker–defender dyads in rugby.

Invasion games include more than discrete short-term 1 v 1 situations. To explore tactical behaviour of interacting players or tactical strategies of teams, there is a need for collective variables that capture the dynamics of ball team sports during real match-play or small-sided games in training, as representation of match sub-phases of full-sized matches (Davids et al., 2007; Lemmink and Frencken, 2010). Frencken and Lemmink (2008) and Frencken et al. (2011b) showed that centroid positions in longitudinal and lateral direction and surface areas of two soccer teams during small-sided soccer games (4 v 4) provide a sound basis for collective variables that capture the dynamics of attacking and defending in soccer at team level.

The potential of centroid positions to describe the rhythmic flow of attacking and defending was also shown for an 11-a-side soccer match (Lames et al., 2010) and specific game situations in basketball (Bourbousson et al., 2010b). These findings are in line with general aims of the game, as such patterns reflect the goal of the two teams moving up and down the field to arrive in scoring positions or prevent that from happening (Gréhaigne et al., 1997). From a dynamical system perspective, research is needed to explore if variability in inter-team distance (i.e. distance between teams’ centroid positions) reflect perturbations that precede critical game events.

### Data collection

In this section, we address technological innovations that have resulted in advancing (semi) automatic tracking systems. This means that positional data of training and matches is become-
ing available rapidly in different ball team sports, especially soccer. Up to date, three different tracking technologies can be distinguished: (semi-)automatic video tracking, Global Positioning Systems (GPS) and electronic tracking. Each of these technologies comes with its own pros and cons. Recently, other technologies for player tracking have been proposed, including the use of infrared-textile (Silva *et al.*, 2011) or pressure-sensitive floors.

Video-based systems, such as ProZone®, AMISCO Pro® or SportVU, generally require the installation of multiple cameras covering the whole playing surface. Extensive calibration procedures ensure overlap between camera images, which in turn allows for calculation of player positions from the camera viewpoints. An operator is required to improve tracking accuracy and real-time availability of data is restricted. Differential or non-differential GPS-based tracking systems (e.g. GPSports) make use of satellites to calculate player positions. Players need to wear a vest or belt containing a sensor that communicates with orbiting satellites. Its use is limited to outdoor activities only because of poor indoor signal reception. In outdoor conditions, signal reception is seriously influenced by satellite positions and weather conditions. Yet, it is the most affordable tracking technology at this moment.

Electronic tracking systems operate in a similar way to GPS. However, tracking takes place in a confined volume with local receivers surrounding the playing surface. Electronic tracking systems, such as the local position measurement (LPM) system (Figure 8.1), require tagging players electronically by way of a vest that contains antennae and a transponder to track players’ movements by means of radio frequency signals. However, electronic aids and other equipment for players necessary for tracking purposes are not allowed in official soccer games currently, thus restricting applicability to training settings. When evaluating physical performances of athletes from kinematic data, the advantages and disadvantages of tracking systems are well documented (e.g. Barris and Button, 2008; Carling *et al.*, 2008; Dobson and Keogh, 2007), but this same information is lacking concerning evaluation of tactical performance.

**Figure 8.1** Schematic representation of the hardware setup of the local position measurement (LPM) system
Beyond the advantages and disadvantages of the different technologies, the quality of data provided is important in evaluating performance, and validity and reliability play a prominent role in this regard. In terms of the former, differences are observed across technologies (e.g. Edgecomb and Norton, 2006; Randers et al., 2010). Most frequently, tracking technologies are validated by players that walk or run predetermined distances. The distances covered measured by a tracking system are subsequently compared to the actual distances that serve as the ‘gold standard’. The scientific evidence generally indicates high degrees of agreement between the gold standard and the tracking system, regardless of the technology (e.g. MacLeod et al., 2009; Di Salvo et al., 2006; Frencken et al., 2010; Varley et al., 2012). However, when systems are compared with each other, significant differences are observed for a series of variables, including total distance covered. This observation holds for comparisons of video systems and GPS systems (Randers et al., 2010) and also when GPS systems are compared to video systems (Edgecomb and Norton, 2006; Randers et al., 2010). This finding leads to the notion of systematic errors, indicating that these systems cannot be used interchangeably. Because of limited availability of electronic tracking systems, similar comparisons have not yet been completed with the possibility of systematic error also present when contrasted against other measurement systems.

Limited data are available on the reliability of the various technologies. Hand-based video tracking systems tend to demonstrate good values of inter- and intra-user reliability in collecting positional data (e.g. Serrano and Fernandes, 2011). Likewise, high levels of absolute and relative reliability were observed for a computerized video tracking system (Di Salvo et al., 2006). However, less convincing results are present for GPS devices, as considerable differences are observed between devices of the same technology, although differences tend to be smaller when new and high-frequency GPS devices of 10 Hz are concerned (Varley et al., 2012). No reliability data are available yet for electronic systems.

Two other important aspects of tracking systems need to be addressed. First, accuracy of measurement is reported seldom. Second, tracking systems have difficulty in measuring players’ positions at high running speeds (Coutts and Duffield, 2010). The relatively low sampling frequency of frequently used devices has been identified as a primary cause of this difficulty (Frencken et al., 2010). For example, Global Positioning System units’ sampling frequency varies from 1 to 10 Hz, whereas semi-automatic video tracking varies between 15 and 25 Hz and electronic systems generally start at 25 Hz or higher. Sampling frequency refers to the temporal resolution, whereas accuracy more generally speaking refers to the spatial resolution of a system. In order to provide meaningful answers to a wide variety of research questions or practically oriented issues, both temporal and spatial resolution of tracking systems need to be considered.

For evaluation of tactics or patterns of play, it can be argued that both the temporal and the spatial resolution of positional data need to be high. Most likely, in specific game situations like free kicks, a few centimetres may determine the correct or incorrect relative position of the player. Furthermore, as tactics are strongly related to position of the ball in the field, it is clear the ball position needs to be incorporated in data collection and data analysis. To date, various technologies are unable to accurately track ball position and, as such, no evidence has been provided on ball position. Currently, the only way to collect ball data is after a time-consuming post-processing procedure. While accurate ball data are not yet available, first attempts in tactical game analysis have nonetheless been realized.

### Game analysis

Analysis of tactics and tactical aspects of soccer can take place at different levels. Individual player level may imply the 1 v 1 opposition relationship between an attacker and defender, say,
or the cooperation between two attackers or two defenders. The next level involves subunits of a team that can be represented by small-sided games, like 4 v 4 or 7 v 7. The final level in soccer is 11 v 11 and comprises a full-sized match. Examples of each of these levels follow.

As discussed before, Araújo et al. (2004) examined positional data of an attacker and defender in basketball-specific exercises. They revealed symmetry-breaking processes, measured by distances between players and distances to the basket. It was demonstrated that, prior to the moment the attacker moves towards the basket, the attacker interacts with the defender to explore options by making small forward and backward movements. One may assume, by means of visual inspection, that these movements are of oscillatory nature. Dynamical systems theory offers tools for analysing this type of data by means of phase relations. In this respect, it has been suggested that a player with a lead phase relation has an advantage over the player with the lag phase relation (McGarry et al., 2002) and, as such, it may be taken as a measure of dominance (Palut and Zanone, 2005).

Extending this concept to soccer, it was hypothesized that a lead phase relation of the attacker would increase the chance to score (McGarry et al., 2002; Frencken and Lemmink, 2008). This idea led to an experiment in which ten young, male elite soccer players (17.3 years ± 0.7) participated in three small-sided soccer games (four-a-side, plus goalkeepers) of eight minutes on a 28×36 m pitch. Positional data were collected at 45 Hz per player by means of an electronic tracking system, the local position measurement (LPM) system. From the positional data, accelerations were calculated for each player. Next, all acceleration data of all players were cross-correlated over a moving 2.5 s time window. In addition, time delays were calculated between acceleration profiles for all players (NBody Software, UMCG, University of Groningen). To illustrate for an attacker–defender dyad, if the positive correlation between the acceleration profiles at any given instant is high, it means that players were moving at the same time such that there is minimal delay between the time series. Consequently, a large delay in the time series indicates one of the players waiting and reacting to the movements of the other player. In addition to these analyses, all goals and goal-scoring opportunities in the small-sided games were identified. They were defined as any successful or unsuccessful shot on goal by the attacker. Goals and goal-scoring opportunities were categorized as 1 v 1 situations, slow-build regular attacks, counterattacks and long shots. The attacker was the player that attempted to score, whereas the defender was the closest opponent of that particular attacker. All player couplings were investigated through visual inspection.

In total, 66 goal-scoring opportunities were notated, of which 19 resulted in a goal. Data showed that, for 65 per cent of the goals and goal-scoring opportunities, the attacker is dominant and holds initiative, with no difference observed between goals and goal-scoring opportunities. In addition, it was found that the percentage frequency of attacking initiative decreased with the type of attack from 100 per cent for 1 v 1 situations to 33% for, long-distance shots; see Figure 8.2). From this, we can take that attackers most frequently take initiative prior to goal-scoring opportunities. The absence of small differences between goals and goal-scoring opportunities, however, indicates that whether or not a goal is scored depends on additional factors (e.g. technical ability, goalkeeper’s ability and/or chance).

The task for the attacker in the various types of attack influenced the attacking initiative required. In 1 v 1 situations, the attacker must take initiative more so than in long-distance shots, say, demonstrating that positional data expressed by relative phase can be used to evaluate the degrees of dominance of attackers over defenders. In this case, the focus was on specific events related to goals and goal-scoring opportunities. However, many more 1 v 1 situations happen during matches. Future research must indicate to what extent positional data can contribute in evaluating dominance of players in all kinds of game situations. Also, interactions
of players that may be less prominent to the naked eye can also be subjected meaningfully to dynamic analysis. For example, the central defender of the defending team may walk backwards toward his own goal when the central defender of the attacking team advances up the field while holding the ball. As such, they both move in the same direction and their movements are related. This dependency can be quantified using the methods proposed here.

The next level of analysis concerns clusters of players. One possible representation can be small-sided games. Taking all players of one team into account facilitates new types of analyses – for example, examining the interactive behaviour between teams. Often, the positional data of outfield players of one team are combined for this purpose. This leads to new types of parameters per team, such as the area of the field covered by a team, the geometrical centre of a team (i.e. centroid position; Figure 8.3) and the stretch index (see Bourbousson et al., 2010b, and Frencken et al., 2011b for detailed calculations). These measures are thought to reflect the rhythmic flow of attacking and defending in soccer. To illustrate, the centroid position is the average x–y position of all outfield players of one team. If the centroid position is calculated for both teams at each instant and the two teams represented by two dots then the rhythmic flow between teams attacking and defending may be visualized. In Figure 8.4, exemplar longitudinal data of both centroids are demonstrated in a small-sided game. It can be seen that both teams move up and down the pitch simultaneously, supported by high positive correlations between the centroid positions of both teams (Frencken et al., 2011b). The same is true for the lateral motion of the centroids of both teams (not shown), although correlations were slightly lower compared to the longitudinal component. These findings are consistent for multiple small-sided games. Strong positive correlations indicated the predominant interaction between centroid positions as in-phase. In addition, specific patterns between centroids related to game events demonstrated the centroids swapped (crossed) positions prior to half of the goals and goal-scoring opportunities. That means the centroid of the attacking team moved past the centroid of the defending team, in similar fashion to the basketball example reported by Araújo et al. (2004). As such, the collective motion of one team relative to the other could be an important performance indicator of tactical game behaviour.

Similar to centroid position, the stretch index and surface area are measures of team interaction. Players of the team in possession open up space and increase interpersonal distances, whereas, in contrast, the team not in possession ties up space and decreases interpersonal distances. If the ball changes teams then so does the dispersion characteristics. Therefore, an anti-phase relation could be expected for these player dispersion measures, although
Figure 8.3  a) Player positions (GK = goalkeeper, DF = defender, MF = midfielder, ST = striker) and relation of centroid (c) and surface area (black and dashed line) measures for the two teams; b) calculation of measures for centroid position (black dot, r = radial distance, x = x-distance, y = y-distance) and surface area (L = length, W = width, SA = surface area)

Figure 8.4 Exemplar time series data of centroid positions in a four-minute small-sided soccer game. Black and grey lines distinguish between teams
scientific evidence is not widely available in this respect and needs further inquiry (Frencken et al., 2011b). Results thus far, however, have demonstrated that relative measures can be developed to describe the status of the system and give valuable information on tactically relevant concepts based on measures like centroid positions and player dispersion. Also, longitudinal and lateral inter-team distances can be considered and expressed in absolute instead of relative terms. That is, the absolute differences between the longitudinal or lateral components of the centroid positions of both teams, as well as surface area, could prove valuable measures of performance in future.

Analogous to analysis of interactive behaviour of teams in small-sided games, full-sized matches (11 v 11) can be evaluated. The reason for this is that, from a tactical perspective, it is unclear to what extent small-sided games reflect full-sized matches. Because players act under different constraints when playing small-sided and full-sized games, it might be expected that interaction patterns differ as well. Bearing this in mind, an additional step can be taken in terms of analysis. Based on the evidence currently available in the context of different team sports (e.g. Bourbousson et al., 2010b; Frencken et al., 2011b; Lames et al., 2010), it appears that full-sized matches adhere to and exhibit traits of dynamical systems. If this is the case, then critical game periods can be established mathematically and predictions can be made based on dynamical systems theory. From this perspective, if centroid positions of two teams reflect the rhythmic flow of attacking and defending, and if this is a tactically relevant construct, then critical tactical game periods could be extracted from the positional data of the teams. Such critical game periods can possibly be identified by calculating variability of inter-team distances, especially given evidence currently available from small-sided games in which cross-over patterns were observed prior to goals and goal-scoring opportunities.

A similar approach was applied to one half of a women’s soccer game (Frencken et al., 2011a). The assumption was that teams’ interactive behaviour could be described through the distance between the centroid positions and that sudden changes in this measure would be indicative of specific match events, like goal-scoring opportunities. For this purpose, positional data of an elite female soccer match were collected at 45 Hz with the local position measurement (LPM) system. For both teams, the centroid positions were determined from the average coordinate data of the outfield players. Subsequently, inter-team distance (ITD) was calculated in longitudinal (ITDX) and lateral (ITDY) direction and variability obtained from standard deviation over a moving 2.5 s window. This time window was considered reasonable for players to react to changing game conditions following consultation with five professional licensed soccer coaches. Critical periods in game dynamics were marked if variability exceeded a sample-based criterion value equal to three standard deviations of the variability signal. Time stamps of the extracted critical game periods were mapped to match events using qualitative video analysis. A similar approach was taken by Frencken et al. (2012).

Results reported 60 critical game periods, of which 24 and 36 were based on high variability of ITDX and ITDY, respectively. Video analysis of the 24 critical game periods extracted from ITDX were predominantly associated with forward passes (n = 5) and dead-ball situations, like throw-ins and free kicks (n = 8). It was unclear from game event observation what the trigger was for the high variability of the remainder of the critical game events. Likewise, the critical game periods extracted from ITDY were predominantly associated with dead-ball situations (n = 13) and sideways passing (n = 26). Because some free kicks were lateral passes over longer distance, these events were categorized in both dead-ball situations and sideways passing.

The results of Frencken et al. (2011a) did not replicate those of small-sided games (Frencken et al., 2011b). As such, it appears that, in full-sized games, periods of high ITD variability do not precede goals and goal-scoring opportunities as with small-sided games. One explanation could
be that the equal contribution of all players to the centroid positions causes variability to dissipate somewhat in full-sized games as compared with small-sided games. Because in small-sided games only four players per team contribute to centroid calculations, their influence on centroid position is greater compared to full-sized games. Therefore, the development of a mechanism that includes ‘active’ players in game situations may be appropriate. An alternative explanation is that the dynamics in small-sided games are indeed different from those of full-sized matches. If so, this would be important because small-sided games are frequently used for tactical training purposes for full-sized matches. Further research is needed to explore these ideas in future.

**Future directions**

Some important issues have to be addressed before practical implications for training can be determined. First, there is a strong need to capture the dynamics of interpersonal interactions during match-play in ball team sports in relation to successful performance (i.e., critical moments in the game). Some promising variables have been suggested and explored (e.g., relative phase of player positions or speeds at the player dyad level and variability of inter-team distance for team dynamics). Yet more research is needed to confirm these initial findings. Second, to advance tactical behaviour practice of players, there is a need to find out if the dynamics of different types of training (e.g., 1 v 1, 2 v 1, small-sided games, etc.) are reflected in full-sized matches. An interesting issue concerns whether and how task constraints like number of players or environmental constraints such as pitch size affect team dynamics. Third, personal constraints (e.g., physical, technical and psychological characteristics) should also be incorporated in analysis of tactical behaviour in small-sided games or real matches. For example, fatigue may influence distance between player dyads at the end of a match, or technical players may need less space and time to control the ball and/or dribble past a defender. Also, psychological mechanisms (e.g., perception of others, social relations, etc.) may influence player interactions during match-play and should be given due consideration in future.

**Concluding remarks**

New technologies like semi-automatic tracking methods based on video or GPS-like technologies, allow for high-frequency position data collection on a regular basis during training and matches. These data sets permit physiological analysis, allowing assessment of physiological load of individual players in terms of distance, speed, acceleration, deceleration and directional changes, not only in relation to performance but also in regard to injury risk (prevention) and rehabilitation programmes (treatment). Position data with high temporal–spatial resolution of different players also permits analysis of interactions of players (‘where and when’). A dynamical system approach seems a promising framework to study these complex interactions between players and teams in ball team sports. This approach may lead to new insights into the interactions of players within different ball team sports.

To facilitate research in tactical performance analysis, an integrated approach is called for. Coaches and trainers should work on a structural basis with scientists from different disciplines (e.g., sport scientists, sport psychologists and statisticians). From a coaching perspective, it is important to unravel tactical aspects, such as applying pressure, transition play between attack and defence, passing opportunities and so on, and define guidelines for training as well as developing tactical strategies for real match-play. From a science perspective, it is important to continue to search for collective variables that describe the dynamics of players during training and match-play. These perspectives should be combined to understand and improve tactical
behaviour of players in ball team sports, including handball, basketball, rugby, field hockey and soccer.

References


