Summary

This chapter describes research on the behaviours of attacker–defender dyads in sports contests from the perspective of ecological dynamics. The main challenge for researchers is to find coordination variables for dyadic systems that accurately describe the mutual interactions between opposing performers that occur in competitive performance environments. In sports, proximity of opponents and teammates means that a significant amount of co-adaptive behaviours can be observed. Ecological dynamics predicts that these interpersonal interactions in competitive performance environments are shaped by self-organizing processes.

A dynamical approach to studying co-adaptive behaviours of performers in sport requires researchers to measure players’ performance continuously, aiming to describe not only ‘what’, ‘when’ and ‘where’ events occur, but also ‘how’ specific patterns of performer interactions might emerge. The coordinative variables used to describe players’ interactions capture different states of coordination that lead to distinct performance outcomes – for instance, when the balance between an attacker–defender sub-system remains or when that balance is broken with clear advantage to one performer over the other. Research evidence has revealed movement variability as a key platform for dyadic system interactions in sports, consistent with the existence of self-organizing processes.

Introduction

Experimental research on the behaviours of attacker–defender dyads in individual and team sports has developed significantly during the last decade. Examples include the work of: McGarry et al. (1999) in squash; Palut and Zanone (2005) in tennis; Lagarde et al. (2006) in boxing; Araújo et al. (2003) in sailing; Passos et al. (2008, 2009) in rugby union; Araújo et al. (2002), Cordovil et al. (2009) and Bourbousson et al. (2010) in basketball; and Headrick et al. (2012) and
Lopes et al. (2012) in soccer. In the following sections, we consider the findings of this body of work in different performance contexts. The first section introduces the issue of representative design, the next section addresses research on individual sports and the last section reviews findings of studies on team sports.

**Representative design**

The concept of representative experimental design proposed by Brunswik (1952, 1956) focuses on the participant–environment interaction and ‘refers to the arrangement of conditions of an experiment so that they represent the behavioural setting to which the results are intended to apply’ (Araújo et al., 2007: 72; Hammond and Stewart, 2001). Thus, Brunswik argued that removing natural variability in experimental task conditions which participants otherwise encounter in performance settings is to remove the proper subject matter of research. In sport then, representative design implies that experimental task constraints need to faithfully represent the task constraints of a specific performance environment (Pinder et al., 2011). These ideas suggest that in experimental settings participants must cope with the same multiple, noisy, messy situations that occur in specific performance environments (Araújo et al., 2007), as removing these naturally-existing phenomena in order to gain greater ‘control’ in experimental conditions (internal validity), consistent with reductionism, leads to artificial constraints in experimental design (Davids et al., in press). In this view, a good way to extend understanding is to faithfully represent the dynamic circumstances that naturally occur in specific performance environments in experimental settings. Without representative design, the behaviours that emerge may not be functional for performance in sports contexts (Dicks et al., 2008; Davids et al., in press; Pinder et al., 2011). Thus, a significant challenge inherent to experimental design is to develop task constraints that are representative of specific environments. In sport performance analysis, a key issue therefore is to consider how affordances (opportunities for action) and/or behaviours in an empirical study correspond to those affordances that exist in a competitive performance setting.

The notion of task representativeness is predicated on what a particular experimental task affords a participant. An affordance requires that a performer regulates his/her activity according to information concerning both an object and/or an event (e.g. ball, opponent, pass, etc.) (Araújo et al., 2007). Hence, affordances, behaviour and, consequently, the representativeness of the experimental task are likely to vary, being shaped by continuous interacting participant, task and environmental constraints (Kugler et al., 1982; Newell, 1986). Different sources of perceptual information allow different possibilities for action (i.e. affordances) (Fajen et al., 2009) and representing the information available for action is an important challenge for researchers in considering experimental design (Araújo et al., 2007). For example, an important question concerns the use of static or dynamic tasks. According to Pinder and colleagues, static task constraints in sport science experiments typically lack functionality and are not representative of performance requirements in dynamic competitive environments (Pinder et al., 2011). Constraints manipulation, however, is a powerful research approach in which to design experimental dynamic tasks that afford the individual the same possibilities of action that he/she will encounter in performance environments.

**Standard vs in situ experimental task designs**

Traditionally, experimental designs tend to emphasize static and ‘decomposed’ tasks which are intended to provide controlled simulations of performance environments. In these experiments, participants are typically required to perform only a simple action to represent more
complex actions (e.g. button press or joystick to represent movements such as a tackle or pass, etc.). In some studies, participants make verbal reports only on what they would do in a given task context. For example, from video analysis of penalty kicks in soccer, a goalkeeper might be tasked with predicting the direction a penalty shot will be directed at. This type of experimental design is adopted in order to exert greater control over the variables under analysis. This standard experimental design is perceived to maximize control of manipulation of independent variables to observe changes in dependent variables. For instance, if the aim is to measure the distance from a defender that an attacker might start performing evasive manoeuvres to avoid being tackled in rugby union, a contact heavy bag might be used to represent the presence of the defender in simulation. Under these experimental conditions, it is possible to record the distance at which the attacker (ball carrier) begins to perform evasive manoeuvres and, also, what sort of action might emerge. Additionally, to measure the influence of the initial conditions during attacking performance, experimenters can manipulate the initial starting distances between the participant (i.e. the ball carrier) and the defender (i.e. the static tackling bag).

The perceived advantage of this type of experimental design is that researchers can accurately measure the influence of independent variables on dependent variables. A clear limitation, however, is that any relationship that might emerge between variables (e.g. the initial starting distance and the distance that the ball carrier begins to perform evasive manoeuvres) is only representative for this specific task. Generalization of the results, therefore, can be problematic. When performance conditions are made more natural, such as replacing the static tackling bag with an active defender who can actually tackle the ball carrier, investigators are altering the possibilities for action. Using artificial task constraints, such as a defensive bag, provides affordances that differ from those that are available for the ball carrier in practice and competitive environments. Of course, an important reason is that a tackling bag does not move or change direction towards the ball carrier, like a defender to make a tackle. The affordances available in a ball carrier–tackling bag simulation interaction are thus different from the affordances that emerge in a ball carrier–defender interaction on-field. This example demonstrates the standard approach to experimental design that is not representative of competitive performance contexts.

Contrary to standard experimental approaches, and supported by the theoretical framework of ecological dynamics, in situ experimental designs promote the representative design of tasks that maintain the coupling of information and action in participants. Key concepts such as constraints and affordances are useful for designing an experimental task that contains constraints that represent performance environments, allowing description of stability and/or variability that characterizes different states of performance. Indeed, the performance stability/variability balance is a key issue since it allows characterization of the state of coordination among system components in sports, such as players in a dyad. When an attacker–defender system is stable, the implication is that neither player is providing a strong perturbing influence on the system. Increased variability in behaviours of a dyadic system, however, signifies that one of the components (i.e. the attacker or the defender) is attempting to gain an advantageous position to achieve a task goal, such as score a goal/try or regain ball possession. These fluctuations in dyadic system behaviours can be identified by recording coordinative variables that accurately capture system dynamics.

To recap, an important advantage of an ecological dynamics approach, which emphasizes representative task design of in situ experiments, is that the results can be extended to understanding performance in real-world contexts. Performance is studied as it emerges and, typically, there are no attempts to control precisely the performance variables under analysis – for example, through prescriptive task instructions. Instead, use of general instructions allows behaviours to emerge through interpersonal interactions of participants. Going beyond the level
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of emergent behaviours to a more predictive level, however, is challenging in that researchers can manipulate variables that might alter the affordances available to the performer (player). The concept of ‘action fidelity’ introduced by Stoffregen and colleagues (Stoffregen et al., 2003) has proved useful in confronting this challenge. In this approach, Araújo et al. (2007) have suggested the need to measure action fidelity variables, such as the time that it takes to complete a task, among other variables that capture states of coordination among system components. Similar values and patterns between ‘laboratory’ and ‘field’ indicate task representativeness and suggest the same possibilities of action in both settings. It is worth noting that the coordinative variables presented next exemplify some possible measures of action fidelity.

Dyadic behaviour analysis in individual sports

**Squash**

The study of McGarry and colleagues (1999) attempted to formally describe the dynamics of squash dyads in competitive settings, concluding that the interactive behaviour of opponent players within a dyad can be usefully described as a dynamical system. These authors captured the performance of both players in the dyad from video camera using a hand-held stylus and graphics tablet to track their movements. Performance data were analysed statistically with correlation coefficients that reported a single state (anti-phase), with periods of instability introduced by way of perturbations characterizing the behaviour of the dyadic system as a dynamical system. This research approach opened a window onto one of the most challenging issues in sport sciences: understanding the balance between stability and instability in performance behaviour.

**Tennis**

Similar to the research of McGarry et al., Palut and Zanone (2005) described the interactive behaviours of tennis players as coupled oscillators, signifying that the players’ interactions on court achieved two different states of coordination: synchronized movements in the same direction (in-phase mode) and in opposite directions (anti-phase mode). In their study, the authors successfully used relative phase as a collective variable that accurately described how the players’ movements were coordinated on court, and also when they transited from one mode of coordination to another. State transitions were observed, accompanied by enhanced fluctuations in the collective variable, and again the stability–instability balance was revealed as a paramount issue in analysing behaviours of interactive dyads in sports.

**Boxing**

A study by Lagarde and colleagues investigated the behaviours of boxers as a dyadic system (Lagarde et al., 2006). Data collection during performance was achieved with videogrammetry using a digital video camera that recorded the boxers’ motions at 50 Hz. The boxers’ bidimensional coordinates were extracted semi-automatically using video-markers and a head motion measure used to describe interpersonal coordination. The data revealed that, despite the ‘random’ motions of the boxers, the mean value of head radial distance (i.e. the distance of each head in the boxing dyad to the mean point between heads) fluctuated between periods of contraction and expansion. Using a symbolic configuration scheme that captured the macro configurations of the boxer–boxer dyadic system, the authors concluded that preferred modes
of interaction depended on the rates of change of head radial distance. Moreover, the results demonstrated that particular configurations of interactive behaviour between performers were achieved based on head velocity of boxers from instant to instant. This observation was supported across a wide set of combined individual actions, leading the authors to suggest the existence of system degeneracy (Lagarde et al., 2006). Degeneracy is a key property in the complexity sciences and recognizes that systems can use different solutions for achieving the same performance outcomes (Edelman and Gally, 2001). In the study of complex dyadic systems in sport, degeneracy signifies that, due to the need for continuous adaptive behaviours by performers, different forms of interactive behaviours can achieve the same performance outcomes (Lagarde et al., 2006).

Sailing

In sailing, a sport with different task constraints to previous research, Araújo et al. (2003) analysed the behaviours of two competing boats during the racing start in a regatta. Due to wind shift tendencies in both intensity and direction, and the positioning of opponent boats during the start period, each crew needed to perform continuous adaptive manoeuvres, aiming to achieve the most advantageous position at the instant of starting. In this research, the authors investigated the angle between the wind direction and the starting line, with the intention of analysing how this system parameter influenced the decision-making behaviours of competing sailors (Araújo et al., 2003). The data revealed preferred zones for starting the regatta close to the extremities of the starting line and zones of high instability in the middle of the starting line. Moreover, Araújo and colleagues provided a formal mathematical description of the boats’ dynamical behaviours using the model of Tuller et al. (1994). This modelling allowed Araújo et al. (2003) to characterize the extremities of the starting line as attractors, or preferred states of behaviour in the start of a sailing regatta.

Dyadic behaviour analysis in team sports

Basketball

The behaviours of competing players in dyadic systems have also been investigated in team sports performance. Araújo and colleagues (2002) proposed the distance of an attacker and defender to the basket (i.e. the medium point of the attacker and defender to the basket) as a coordinative variable that accurately describes dyadic system behaviours in 1 v 1 basketball. They also proposed interpersonal distance between attacker and defender as a system parameter that, when achieving a critical value, can move the dyadic system towards a specific performance outcome (see also Schmidt et al., 1999) – for instance, an interception of the ball by the defender or a shot at basket by the attacker. The aim of that study was to investigate whether the distance of the dyadic system to the basket became destabilized as interpersonal distance between the attacker and defender decreased. In other words, they sought to understand whether the balance of the attacker–defender dyad was disturbed or broken at specific critical values of interpersonal distance in respect of basket location. The data revealed that the coordinative variable was able to accurately describe different states of the dyadic system – for example, when the defender displayed advantage as judged from being able to maintain dyadic system stability by counterbalancing the attacker’s movements. The data also showed a new system state when the attacker managed to dribble past the defender to move closer to the basket, a system change attributed to symmetry breaking in the attacker–defender relations. The authors identified this
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Abrupt change in the balance of a dyadic system balance as a ‘phase transition’, a general feature of dynamical systems.

The work of Cordovil and colleagues aimed to analyse the influence of task constraints on the symmetry of attacker–defender dyads in basketball (Cordovil et al., 2009). They sought to understand whether the attacker–defender–basket configuration could be disturbed, or even broken, under the influence of common task constraints. In the first experiment, different performance instructions labelled as neutral, conservative and risk taking were given to the attacking players. Interpersonal distances between the attacker and defender were used as a collective variable to investigate dyadic behaviour. Positive values of interpersonal distance signified the defender as closest to the basket and negative values, the attacker. Thus, when the coordinative variable changed from positive to negative, a symmetry-breaking process had occurred with the attacker now acquiring an advantageous position for scoring. The data revealed that conservative instructions led the attackers to increase variability of their running-line trajectories and they took more time to cross the mid-line of the court when dribbling. In other words, the use of different performance instructions changed the attacker–defender balance in dyadic systems, as revealed in the different variability of the attackers’ running-line trajectories. The results also revealed, however, that the three distinct instructional constraints did not influence the frequency of symmetry-breaking occurrences.

In the second experiment of Cordovil et al. (2009), the authors created dyads consisting of different height relations, aiming to analyse whether this individual structural constraint influenced dyadic system behaviours. Contrary to the findings of the first experiment, the data revealed significant differences in the frequency of symmetry-breaking occurrences when the attackers were shorter than the defenders. Also, the time to cross the court mid-line when dribbling the ball was significantly less for shorter attackers, as compared with dyads comprising the same height relations or when attackers were taller than defenders (Cordovil et al., 2009). These findings implied that the height relation between performers in basketball is a task constraint that can influence the balance in dyadic systems.

Staying with basketball, Bourbousson and colleagues (2010) used lateral and longitudinal players’ movement displacements trajectories to analyse interpersonal patterns of coordination. Regarding the attacking–defending dyads, the data revealed strong in-phase attractions in the basket-to-basket (longitudinal) direction. On the contrary, weaker interpersonal coordination was observed within defending and attacking dyads in both longitudinal and lateral directions. In contrast with the preceding results, however, anti-phase coordination in the lateral direction only was reported for dyads comprising wing players from the same team. These varying interpersonal coordination patterns are consistent with the game demands of supporting teammates’ actions in pursuit of team objectives. This research demonstrated relative phase as a powerful collective variable that accurately captures different modes of interpersonal coordination between different dyads.

**Soccer**

Similar to the studies in sailing and basketball, Headrick et al. (2012) analysed the influence of task constraints on behaviour in attacker–defender dyads in soccer. In this study, the authors investigated whether proximity to goal influenced the dynamics of dyadic system behaviours. The task involved a typical 1 v 1 sub-phase of soccer performed in three different locations on the pitch: i) attacking the goal (i.e. edge of the defender’s penalty area; ii) in midfield; and iii) leaving the goal being attacked (i.e. edge of the defender/ball dribbler’s penalty area). Players’ performance was recorded using single video camera at 25Hz and their bi-dimensional
coordinates were extracted manually using TACTO 8.0 software (Fernandes and Caixinha, 2003). The variables under analysis included the distances of both defender and attacker to the ball. Results revealed significant differences in dyadic system behaviours at different pitch locations. Closer to the goal (i.e. at the edge of the defender’s penalty area), the defender-to-ball distance stabilized at greater values than when the attacker–defender interactions occurred further from the goal. In other pitch locations, the defender-to-ball distance stabilized at lower values. The results showed how playing performance was highly constrained by on-field location where the dyadic system interactions occurred. The defender displayed more conservative behaviours closer to goal, whereupon poor decision making could lead to an advantageous situation for the attacker (a possible phase transition) with little prospect of recovery. The study of Headrick and colleagues showed how the behaviours of players in a dyad differed, based on key task constraints as reference points such as distance to goal, highlighting the importance of understanding the player–environment relationship in sports performance analysis.

Following the same line of experimental logic in manipulating task constraints to understand their effects on dyadic system behaviours, Lopes et al. (2012) investigated the dynamic interactions of goalkeeper and penalty taker in soccer. For reasons expressed previously, a major concern of Lopes et al. was to preserve the representativeness of the experimental task design. One way to achieve this goal was through providing instructional constraints that induced variability in the decisions and actions emerging from the interactions between penalty taker and goalkeeper. Thus, aiming to analyse the influence of specific task-related instructional constraints on action strategies and performance outcomes, the behaviours of both players were constrained under five different conditions: i) no specific instructions for penalty taker or goalkeeper; ii) the penalty taker had to choose one of the goal areas to place the ball prior to the run-up, combined with a free strategy for the goalkeeper; iii) the penalty taker had to choose the shot direction during the run-up, combined with a free strategy for the goal keeper; iv) no specific instructions for the penalty taker, combined with instructions for the goalkeeper to stay still as long as possible; and v) no specific instructions for the penalty taker, combined with the goalkeeper being free to move side to side on the goal line. Players’ performance was video-recorded at 25 Hz using a single camera, and their bi-dimensional coordinates were extracted manually using TACTO 8.0 software (Fernandes and Caixinha, 2003).

In a descriptive analysis of the dyadic system under investigation, the coordinative variables selected were movement speed and goal line angles for both penalty taker and goalkeeper. Similar to previous research described in this chapter, the coordinative variables revealed different dyadic system states and sudden transitions between states. Similar to the results obtained by Cordovil and colleagues (2009) in basketball, the different instructional constraints led to differences in the dyadic behaviours of the penalty taker and goalkeeper when competing. However, no differences in performance outcomes emerging from the interactions were observed, implicating and reinforcing the view of system degeneracy as a common feature of dyadic systems in sports.

**Rugby union**

The existence of mutual behavioural dependency between attacker and defender drives dyadic systems to explore different solutions for achieving the same performance outcomes. The work of Passos et al. (2009) in 1 v 1 sub-phases of rugby union near the try line highlighted a coordinative variable that accurately described the interactive behaviours between attackers and defenders. That coordinative variable was angle calculated with a vector from defender to attacker referenced to a horizontal line parallel to the try line. Similar to previous research, the coordinative
variable in rugby union also characterized two different states of the attacker–defender system, as well as transitions between those states. Positive angles signified the defender was the closest player to the try line, a zero-crossing identified the transitional moment that the attacker drew level with the defender, and negative angles signalled emergence of a new system, whereupon the attacker had moved past the defender to become closest to the try line (Figure 6.1).

This coordinative variable allows description of the interactive behaviours of attackers and defenders in rugby union, nevertheless it does not explain why this dyadic system transitioned from an advantage to the defender to that of the attacker. For that purpose, Passos et al. (2008) suggested two candidate system parameters: interpersonal distance between attacker and defender, as before, and relative velocity of the players. Results revealed that these two system parameters acted in a ‘nested’ way. Specifically, decreasing interpersonal distance values attracted the attacker–defender system to a critical region whereupon players’ behaviours become mutually dependent, and within that critical region the influence of relative velocity between players had a powerful effect, serving to move the dyadic system to one of the two preferred states. Put simply, if relative velocity in the critical region was increasing, the attacker was advantaged, and if it was decreasing, the advantage was with the defender.

Concluding remarks

In the first part of this chapter, the concept of representative design was introduced (Brunswick, 1952, 1956) and a constraints-based approach for investigating sports behaviours advocated. It was suggested that experimental task designs manipulate task constraints specific to each sport,
thereby replicating the affordances available to players in competitive performance settings. In fact, the implication of this proposition goes beyond results transfer from experiment to performance environment, as argued here, and extends more generally to consideration of design in training and learning programmes in sports practice (Araújo et al., 2007).

The studies reported in this chapter have strived to meet the requirement of representative design and document some of the research in dyadic system behaviours in sport over the past decade. They have in common the need for identifying coordinative variables that describe the interactive behaviours of performers, rather than describing the behaviour of each player as a single entity divorced from the other. The use of coordinative variables allows identification of stable states in dyadic systems, such as when a defender maintains an advantage over an attacker. These coordinative variables also describe when the attacker–defender balance is broken and a new stable state emerges, a phenomenon called phase transition. These same variables have also identified intra-system variability in support of the notion of system degeneracy, explaining how players’ interactions display different solutions for achieving the same performance outcome. In the aim of advancing understanding of phase transitions in dyadic systems, some studies have gone beyond coordinative variables and suggested candidate variables as system parameters. Successful examples include the studies of Araújo et al. (2003) in sailing and Passos et al. (2008) in rugby union. These investigations have thus far indicated interpersonal distances, velocities and angles as important system parameters of dyadic system behaviour. The results presented in this chapter offer continuing evidence in support of the notion of competitive sports performance as self-organizing processes based on the theoretical framework of ecological dynamics.

References


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