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From recording discrete actions to studying continuous goal-directed behaviours in team sports

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Abstract
This paper highlights the importance of examining interpersonal interactions in performance analysis of team sports, predicated on the relationship between perception and action, compared to the traditional cataloguing of actions by individual performers. We discuss how ecological dynamics may provide a potential unifying theoretical and empirical framework to achieve this re-emphasis in research. With reference to data from illustrative studies on performance analysis and sport expertise, we critically evaluate some of the main assumptions and methodological approaches with regard to understanding how information influences action and decision-making during team sports performance. Current data demonstrate how the understanding of performance behaviours in team sports by sport scientists and practitioners may be enhanced with a re-emphasis in research on the dynamics of emergent ongoing interactions. Ecological dynamics provides formal and theoretically grounded descriptions of player-environment interactions with respect to key performance goals and the unfolding information of competitive performance. Developing these formal descriptions and explanations of sport performance may provide a significant contribution to the field of performance analysis, supporting design and intervention in both research and practice.

Keywords: decision-making, information, action, interpersonal interactions

Introduction
In team sports, athletes are the key actors in a dynamic performance environment, continuously interacting with each other to achieve performance goals. While an attacking team (team with ball possession) aims to score (e.g., a try in rugby union or a goal in association football), the defending team aims to prevent opponents from scoring and to regain possession of the ball. Successful performance in sport is predicated on an individual’s perceptual and action capabilities, and is grounded in the information used for action selection and goal achievement (Williams & Ward, 2007).

Research aiming to analyse functional performance behaviours in sport generally relies on three main approaches. Some studies essentially query which information is used by performers of different levels of expertise in team sports (e.g., ice hockey goaltenders, Panchuk & Vickers, 2006). Other studies examine which actions are performed in competitive performance, assessing discrete measures of behaviour commonly associated with performance outcome measures (e.g., Hughes & Bartlett, 2002). Finally, there are also studies focused on the coupling of information and action, through the analysis of biophysical (spatiotemporal) variables underlying decision-making and action (e.g., Passos et al., 2008). Here we present and discuss illustrative studies based on each of these approaches.

Manipulation of information during performance influences emergent actions
A particular focus of sport expertise research has been on which processes individuals may use to organise effective performance. For example, recent research has claimed to demonstrate how schemata or action rules (basketball and handball: Fruchart, Pâques, & Mullet, 2010), and information processing and memory interface processes (association football:
Zoudji, Thon, & Debu, 2010), allowed participants to plan and programme actions before performing. In these studies, participants were presented with hypothetical and static images depicting game states. This information was provided in hard copy form outlining attributes such as numerical status in performance sub-phases (Fruchart et al., 2010) or as images presented on a computer screen (Zoudji et al., 2010). Participants were asked to verbally report which game strategy they considered most appropriate or to press a computer keyboard corresponding to the action they would undertake.

In research on visual perception in sport experimenters have relied on temporal and/or spatial occlusion paradigms, and eye movement registration techniques for analysing performance of participants differing in skill levels (for a review see e.g., Williams & Ericsson, 2005). Temporal occlusion methods occlude filmed action sequences during determined time periods requiring participants to verbally report what they believe would happen next. Moreover, these methods usually involve a discrete action response to choose between alternatives (e.g., a button press). Results from this body of work have suggested that experts outperform novices by having the ability to detect ‘cues’ at an earlier time-point in an action sequence (Müller & Abernethy, 2006). Spatial occlusion methods omit information components during the preparation and execution of an action image displayed on a screen (Williams & Ericsson, 2005), examining how the loss of that particular arrangement of information constrains perception and decision-making efficacy. Eye movement registration techniques assess the specific locations on an image where participants fixate, presumably to gain information from the display (Panchuk & Vickers, 2006). With these techniques, discrete eye movement measures such as search rate, latency of saccade, fixation location, fixation duration, number of fixations, and fixation order, are assumed to indicate how sources of information are picked up by participants to support judgments about actions. For example, Vaeyens and colleagues (Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2006) combined visual gaze and occlusion analysis to investigate the relations between visual search behaviours, decision-making, skill and experience level in sport. Participants were presented with near life-size images in filmed sequences of different patterns of play in association football and were asked to simulate a response by passing the ball at an image of a player on a screen, kicking the ball towards a goal, or moving as if to dribble past a defender. Decision-making processes were measured by establishing movement initiation time (gained from pressure-sensitive mats) and response accuracy (rated by expert coaches). Results led the investigators to assume that the cognitive knowledge basis (i.e., memory) of skilled participants support their greater ability to pick up and interpret the consequences of perceptual information for action when compared to less skilled participants.

Virtual reality settings have also been used to investigate information used for perceptual judgments and actions. Results have shown evidence of spatiotemporal optical invariants influencing players’ judgments (by button press, e.g. Craig et al., 2009) and actions (hand movements in the direction of a ball, e.g. Dessing & Craig, 2010) on the trajectory of virtual simulated curved free kicks in association football. Combining virtual reality with the temporal occlusion technique, Watson and colleagues (Watson et al., 2010) studied novice performers as they decided whether or not they could pass successfully between two approaching defenders. They also sought to ascertain which spatiotemporal information sources available in the performance environment could be prospectively guiding participants’ judgments about the opportunities for passing the defensive line. Participants’ responses (i.e., their perceptual judgements) were assessed by a discrete response measure such as a button press.

In summary, although some investigations have been conducted in competitive performance environments, participants’ behaviours have typically been examined under relatively artificial experimental settings. Experimental control is suggested to be important to draw conclusions about the effects of different variables on performance. However, these variables have been generally examined in designs that have decoupled perceptual processes from actions on relevant external objects and events (Fajen, Riley, & Turvey, 2008; van der Kamp, Rivas, van Doorn, & Savelbergh, 2008). Moreover, performance outcome measures are often discrete (e.g., response time, response accuracy, response consistency), describing how actors use ‘cues’ to conduct specific actions or to report judgments on possible actions. Importantly, most studies have tended to examine where and when athletes detect ‘cues’, but there is little systematic research about how performers use information throughout the course of action during goal-directed performance.

**Individual or collective performance in sport is traditionally defined by recording discrete actions**

Team sports performance has been analysed by seeking to record the type of actions that are performed in a competitive game. This approach has been commonly operationalised by also considering discrete measures of action (e.g., goals, winners, errors, turnovers, tackles, passes/possession, and
dribbles) (Hughes & Bartlett, 2002). The aim has typically been to catalogue which actions are performed, who performs them, and where those actions take place, defining coordination patterns through the summary of isolated discrete categories of actions recorded in a sequential fashion (e.g., who[did]-what-where-when). These measures, whether considered over time (as in sequential analysis studies) or not (as in notational analysis), have been categorised to describe successful or unsuccessful performance behaviours in sport.

Researchers have described goals scored in association football by associating this outcome measure to each team’s ‘style of play’, that is, with data from passing sequences in different matches (Hughes & Franks, 2005). Jones, James, and Mellalieu (2004) examined teams’ ‘ball possession’ in association football as a function of the evolving match status (i.e., winning, losing or drawing) (for research on evolving match status, see also e.g., Lago & Martin, 2007). Results showed that successful teams displayed significantly longer periods of ball possession than unsuccessful teams. However, when match status was not considered, both groups displayed longer periods of possession when losing than when winning. Data from this study were interpreted as a consequence of differences in skill levels of individual teams instead of specific team strategies adopted.

Other research on match performance has focused on distinct aspects of performers’ actions, either at an individual or team level, such as players’ movement displacement trajectories during competitive performance (e.g., Carling, Bloomfield, Nelsen, & Reilly, 2008; O’Donoghue, 2008), patterns of events (e.g., Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004), occupation of different spatial areas of the field by individuals or teams (e.g., Gréhaigne, Bouthier, & David, 1997), and effects of game venue on performance outcomes (e.g., Jones et al., 2004; Lago & Martin, 2007).

In summary, this line of research has described decision-making performance by recording the patterned frequency of discrete actions in association with key events. Current technological developments (such as the increased capacity of different match analysis software packages and remote sensing technology) may facilitate data collection and online analysis of performers’ actions on a massive scale. Whilst a large number of descriptive studies have created awareness among athletes and coaches of how individual players can influence team patterns, research using these data has tended to neglect the role of the ecological constraints in which performance occurs (Vilar, Araújo, Davids, & Button, 2012). Particularly, little attention has been paid to how actions emerge from the continuous interactions between performers and the environment, i.e., what were the circumstances that made a particular action possible.

Performers’ interactions express goal-directed behaviours to satisfy performance constraints

Recently, increasing interest is being paid to understanding how performance in team sports is predicated on interpersonal interactions between attackers and defenders as they act to satisfy spatiotemporal constraints of performance (Araújo, Davids, & Hristovski, 2006). This has been the concern of a substantial programme of work from an ecological dynamics perspective (see some examples in Table I) and focuses on identifying biophysical relational measures between players and key task constraints (e.g., location of the goal and the ball) that shape decision-making and action. As follows, manipulation of task constraints (information) and motion analyses methods have been used to collect time series data on the displacement coordinates of players and ball. By showing statistical relationships between the information of the performance environment and behavioural outcome measures, researchers have provided evidence on how players support successful performance through the use of that information. Motion analysis methods help to identify players’ performances in a continuum and transitions in their course of action during competitive performance. For example, Correia and colleagues (Correia, Araújo, Craig, & Passos, 2011) used motion analysis techniques to show that the time for the gap between the ball-carrier and the defender to close (time-to-contact) constrained the type of pass (short or long) performed in a competitive rugby union match. Likewise, during competitive performance, other recent studies have shown, for instance, how players perform successful passes (Travassos et al., 2012) or shape opportunities for goal scoring (Vilar et al., in press) in the team sport of futsal.

Also using process-tracing methods, Araújo and colleagues (Araújo, Davids, Bennett, & Chapman, 2004; Davids, Button, Araújo, Renshaw, & Hristovski, 2006) examined 1vs1 sub-phases in basketball and showed that a phase transition in the players’ distance to the basket precipitated sub-phases in basketball and showed that a phase transition in the players’ distance to the basket precipitated a dribble. Functional actions were suggested to emerge as previous stable attractors became unstable forcing the dyadic system to adopt a different pattern of coordination. In rugby union it has been demonstrated that the collective behaviours of attacker-defender dyads could also be explained by the dynamics of an angle defined between an attacker, his direct defender and the try line (Passos et al., 2009). In that study, data verified that the relative velocity of the ball carrier...
and a marking defender, nested within a specific value of the interpersonal distance between the performers, indicated the critical threshold beyond which a phase transition in the dyadic system could occur (Passos et al., 2008) (for similar findings in association football see Duarte et al., 2010). In basketball, Esteves and colleagues (Esteves, Oliveira, & Araújo, 2011), investigated decision-making of performers regarding the drive towards the basket. Their results demonstrated that the direction of the drive was constrained by the posture of a marking defender and scaled to an intrinsic metric of the attacker-defender system (i.e., emerged at particular interpersonal distance values between these players). These studies provided understanding on how players interact with the performance environment to create and use information to support successful decision-making and actions. Table I presents how variables in each study accessed qualitative changes in the state of the systems. The data suggest that it would be interesting in future research to check whether some of these variables are dependent on each other. This relationship would produce a further reduction of the dimensionality of the space of essential (collective) variables and refine the dimensionality of the state space for each particular task.

In summary, in an ecological dynamics programme of work, the relations between the perception of informational variables and action are crucial...
for understanding the underlying processes of decision-making in team sports. The research designs highlighted aimed to assess how performers adapted their actions in an ongoing manner according to their own action capabilities and performance goals. Action adaptations allow performers to explore and detect what actions are possible in their unfolding interactions with key aspects of the performance environment (including key events, significant others and spatial locations of the playing area). It is important to note that the perception of these action possibilities (also known as affordances, Gibson, 1979) is also dynamic (for examples see Fajen, Díaz, & Cramer, 2011; Weast, Shockley, & Riley, 2011). Performer-environment interactions are analysed with process-tracing methods to examine the emergent dynamics of performance behaviours, their transitions, and their relation with performance efficacy (Duarte et al., 2010; Esteves et al., 2011; Passos et al., 2008; Passos et al., 2009). Notwithstanding the identification of relevant informational constraints on sports performance, studies following this line of research have typically not attempted to actually manipulate these biophysical (spatiotemporal) informational variables. This limitation should be overcome by future research, manipulating, for example, potential informational variables through the use of immersive and interactive virtual reality simulations of performance environments (e.g., Correia, Araújo, Cunnings, & Craig, 2012). The use of this type of interactive technology allows for the precise control of the informational layout of the simulated performance environment, ensuring reproducibility/manipulation of informational variables between trials (see e.g., Bideau et al., 2010).

Decisions are expressed by ongoing and goal-directed player-environment (inter)actions

The just described method focused on the coupling of information and movement is grounded on the ecological dynamics framework. In this last section, we propose that, to better understand decision-making and action in team sports, research should move beyond describing actions or perceptual judgements by recording discrete response measures. Rather it is important to understand how individuals use information sources to guide ongoing goal-directed behaviours during competitive practice and performance (Fajen & Turvey, 2003), as proposed by ecological dynamics. However, in most prevalent methodological approaches in the literature, perception of information sources and actions are not considered as being linked. There is an asymmetric explanatory bias towards studying the ‘discrete actor’ conceiving both processes as ‘actor-centred’, with their basis in organismic constraints (Davids & Araújo, 2010; Dunwoody, 2006).

Traditional research on perception in sport focuses essentially on the use of information for verbal judgments or micro-movements. Conversely, when research is action centred and unpaired movement is considered, decision-making measures are recorded in a discrete fashion, often studied in isolation of sport performance contexts, and distinct from the relevant functional behaviours in those contexts (e.g., overemphasising the role of reaction time to a suddenly presented stimulus). Investigations rarely examine ongoing goal-directed interactions of participants with key performance constraints. For instance, visual occlusion research does not provide interpretation of what information is actually used in decision-making, given that occluded image areas, or the time of occlusion, are typically defined a priori by experimenters and limited to specific display areas. In reality, participants may actually use variations of these experimenter-defined environmental properties. Gaze behaviour analysis also has some notable weaknesses, particularly concerned with the fact that an ocular fixation on a specific location of a visual display is not necessarily related to the use of that environmental property as a source of information to regulate action (Huys et al., 2009). Maintaining gaze in a particular region may involve ‘visual anchoring’ and the pick-up of peripheral visual information (Nougier, Azemar, Stein, & Ripoll, 1992).

Another issue to consider is related to the generalisation of results (Araújo et al., 2006). Although investigators have been increasing the involvement of action in virtual reality simulation studies, they often still do not allow performers to undertake unhampered functional movement behaviours (Dicks, Button, & Davids, 2010). Consequently, different behaviours of participants have been reported when studied under simulation and in situ experimental task constraints (Dicks et al., 2010).

An important consideration is how local interaction rules between players shape global system outcomes. From this perspective it is necessary to identify the relevant variables at a system (e.g., match) and subsystem (e.g., 1vs1 sub-phase) level that express the interactions between players and teams, and influence emergent decisions and actions (Araújo & Davids, 2009). Analysis of stable and unstable patterns of coordination reveal exploratory behaviours of players, i.e., decisions to detect and create information about what actions are possible to achieve specific performance goals (captured by the inherent adaptability of a movement system in seeking stable attractors when they may not be easily available or evident). Perceiving these action possibilities for oneself, as well as teammates and opponents, is a key feature of skilled performance in team sports.
(Araújo & Davids, 2009; Fajen, Riley, & Turvey, 2009). Furthermore, the performance of players and teams may be considered as being ‘conditionally-coupled’ (van Geert, 1994). That is, one discrete measurement of an action at one point in time is dependent on previous observations of that variable, signifying that it should not be studied in isolation (as occurs in traditional team performance research).

In conclusion, although previous research has improved understanding of team sports performance, further work is needed to better understand how excellence in performance emerges.

In this paper we have outlined some common weaknesses in research. We have also provided some illustrative empirical evidence from studies of team sports. Overall, it seems most important to not just focus on specific information sources nor on discrete actions to describe successful performance. An important challenge is to investigate the dynamics of on-going goal-directed (inter)actions of performers in sport, considering their context-dependency, and concurrently assessing what information is being used to support functional behaviours. An important empirical task is to seek ways to manipulate the information constraints in performance environments (e.g., by manipulating task constraints), while maintaining the coupling between perception and action, and examine how performance goals are attained. Investigators should first identify order parameters, that is, collective variables that describe the state of the performer–environment system. An interesting development for future research would be to investigate how collective variables, detected for each task (e.g. those in Table I), contextualise or govern the components (e.g. players) of the system (e.g., a game or game sub-phase), but also how these are constrained by the orderly behaviour of the system components. Additionally, researchers should progressively attempt to manipulate a possible key constraint of this system (i.e., control parameter), identifying features of stability, instability and phase transitions. For instance, it would be worth investigating the behaviour of system components under some mean value of the collective variable far from the critical point and how this relation changes as the system approaches the region of qualitative change. These observed non-linear transitions in the course of action are expected to illustrate the dynamics of decision-making behaviours. In this sense, ecological dynamics is proposed as a valuable framework to study the emergent nature of decision-making from the continuous interpersonal interactions between performers and the key features of the performance environment. Ecological dynamics has the potential to unify different research domains, such as performance analysis, skill performance and sport expertise. More precisely, we have argued how examining performance through stable and unstable performer–environment relationships facilitates convergence on knowledge of ‘which information’ and ‘which actions’ and ‘information and movement couplings’ underpin functional behaviours in sport. This ‘unification’ process is expected to provide impetus to develop understanding of performance in team sports, to counter the contemporary overemphasis on the discrete cataloguing and categorising of behaviours. Ecological dynamics provides an explanatory framework that primarily considers the performer–environment relationship in the design and intervention of both research and practice in studying/developing team sports expertise.

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