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Shaping Decision-Making Behavior by Perceiving the Dynamic Patterns of Interpersonal Coordination in Futsal

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na especialidade de Ciências do Desporto

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Abstract

The aim of this thesis was to investigate the informational constraints that guide performance of individuals and teams in sport. An initial meta-analysis of the effects of expertise on decision-making revealed stronger effects with more homogeneous results in performance contexts and when individuals were allowed to perform sport actions. Based on this conclusion, all of our empirical experiments were developed using a specific sub-phase of competitive futsal games. Analysis of ball passing performance revealed that the decision to pass a ball to a teammate was regulated by spatial constraints through the coupling of interpersonal distance values between players at the moment of pass initiation. Furthermore, the success of the pass was well predicted by a proposed variable defined as Time to Ball Interception. In order to understand how ball dynamics and goal position constrained interpersonal relations between players we also investigated how patterns of interpersonal coordination between players emerged during different sub-phases of the game. It was observed that the ball and the goal represent key performance constraints which shape the emergent patterns of coordination between players and teams. Different coordination dynamics for defenders and attackers were observed, which was consistent with different team objectives In conclusion, all the studies contributed to a better understanding of how individual players or teams adapted their behaviors to the changing conditions of the performance environment, in order to successfully perform.

Keywords: Decision-making, perception-action, affordances, constraints, couplings, interpersonal coordination, expertise, game-dynamics, self-organization, futsal.

Resumo

A presente tese procura compreender a influência de alguns constrangimentos informacionais no comportamento de indivíduos e equipas durante o jogo. A meta-análise realizada para a identificação dos efeitos da “expertise” na tomada de decisão revelou que os comportamentos captados em contextos desportivos ou onde os indivíduos realizam acções desportivas específicas são mais homogéneos. Tendo por base esta conclusão, toda a investigação empírica foi desenvolvida em situações de jogo no futsal. Na análise dos padrões de coordenação interpessoal que rodeiam um passe no futsal, verificámos que esta acção é regulada por constrangimentos espaciais tendo por base os acoplamentos que se desenvolvem entre os jogadores. Verificámos também que o sucesso de um passe pode ser descrito pela variável “Tempo para contacto com a bola” (TBI). Procurámos também explicar como a trajectória da bola e a posição da baliza constrangem o surgimento de padrões de coordenação durante um jogo de futsal. Foi observado que a bola e a baliza representam constrangimentos relevantes para o surgimento de padrões de coordenação entre jogadores e equipas. Por outro lado, diferentes padrões de coordenação foram também observados para atacantes e defesas, de acordo com os seus objectivos. Deste modo, o conjunto dos estudos realizados contribuiu para uma melhor compreensão acerca de como os indivíduos e as equipas adaptam os seus comportamentos às alterações do ambiente para alcançar os seus objectivos.

Palavras chave: Tomada de decisão, percepção-acção, affordances, constrangimentos, acoplamentos, coordenação interpessoal, perícia, dinâmica de jogo, auto-organização, futsal.

Publications

Five papers have been published, accepted for publication, or submitted for publication on the ground of this thesis:

Under Review/In Press

Travassos, B., Araújo, D., Davids, K., O'Hara, K., Leitão, J., & Cortinhas, A. (Submitted). The effect of expertise in decision making in sport – A meta-analysis.

Travassos, B., Araújo, D., Davids, K., & Fernandes, O. (Submitted). Information from performers' positions regulates passing actions in team ball sports.

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Correia, V. (Submitted). Informational constraints on performance of interceptive actions in team sports.

Travassos, B., Araújo, D., Vilar, L., & McGarry, T. (In press). Interpersonal coordination and ball dynamics in futsal (indoor football). Human Movement Science. doi: 10.1016/j.humov.2011.04.003

Travassos, B., Araújo, D., Duarte, R., & McGarry, T. (Submitted). Spatiotemporal coordination patterns in futsal (indoor football) are guided by informational game constraints.

Congress presentations

Some exploratory results of this thesis have been presented in national and international scientific congresses with refereeing and published in abstract books:

Travassos, B., Araújo, D., Vilar, L., Esteves, P., Correia, V., & Davids, K. (2011). Informational constraints to intercept a passing ball in team sports. Book of abstracts. 13th European Congress of Sport Psychology, Madeira, Portugal.

Travassos, B., Araújo, D., Davids, K., Duarte, R., Araújo, P. & Salgueiro, I. (2011) Representative design of passing drills in futsal practices. Book of abstracts. 13th European Congress of Sport Psychology, Madeira, Portugal.

Travassos, B., Araújo, D., Davids, K., Duarte, R., & Vilar, L. (2011). Measuring representativeness of different passing tasks in futsal. Book of abstracts (pp. 207). 7th world congress on science and football, Nagoya, Japan.

Travassos, B., Araújo, D., McGarry, T., Vilar, L., & Duarte, R. (2011). Interpersonal and ball patterns of coordination in futsal. Book of abstracts (pp. 116). 7th world congress on science and football, Nagoya, Japan.

Travassos, B., Araújo, D., Davids, K., Vilar, L., Duarte, R., & Fonseca, S. (2010). Interpersonal and ball space-time patterns of coordination in futsal game. Book of abstracts (pp. 123-124). 3rd International Congress of Complex Systems in Medicine and Sport, 15-18 September, Kaunas, Lithuania.

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Travassos, B., Araújo, D., Esteves, P., Correia, V. & Davids, K. (2010) Spatiotemporal Patterns of Coordination Determines Pass Efficacy. Book of abstracts (pp. 58-59). 11th European Workshop on Ecological Psychology. Fréjus, France;

Travassos, B., & Araújo, D. (2010) Percepção de Affordances para o Passe em Desportos Colectivos. Livro de Actas (pp. 1916-1924). VII Simpósio Nacional de Investigação em Psicologia. Universidade do Minho, Portugal;

Travassos, B., Araújo, D, & Davids, K. (2009) Affordances for passing the ball in futsal. Book of abstracts (pp. 58-59), Progress in Motor Control VII. Marseille, France;

Travassos, B., Araújo, D., Duarte, R., & Davids, K. (2009) Emergence of affordances for passing in futsal. Book of abstracts (pp. 53) European Workshop on Movement Science. Lisbon, Portugal;

Travassos, B. & Araújo, D (2009) An Eco-Dynamic approach for training individual decision making in teams. Book of abstracts (pp.33) 1st International Congress of Psychology and Education. Covilhã, Portugal;

Travassos, B., Araújo, D. & Davids, K. (2008) How Futsal players decide when to pass: Perceiving affordances in competition. Book of abstracts (pp. 100-101) 2nd International Congress of Complex Systems in Sport & 10th European Workshop of Ecological Psychology. Madeira, Portugal;

Travassos, B., Araújo, D., Esteves, P., Correia, V. (2008) Improving the understanding of Team Sports Performance. Book of abstracts (pp. 86-87) 2nd International Congress of Complex Systems in Sport & 10th European Workshop of Ecological Psychology. Madeira, Portugal;

Other publications

Some parallel work was developed with the thesis advisors Dr. Duarte Araújo, Dr. Keith Davids and other PhD students supervised also by the former. From this collaboration resulted the following papers and book chapters:

Travassos, B., Araújo, D., Correia, V., & Esteves, P. (2010) Eco-Dynamics Approach to the study of Team Sports Performance. The Open Sports Sciences Journal, 3, 56-57.

Araújo, D., **Travassos, B.**, & Vilar, L. (2010). Tactical skills are not verbal skills: A comment on Kannekens and Colleagues. Perceptual and Motor Skills, 110(3), 1086-1088.

Duarte, R., Araújo, D., Fernandes, O., Fonseca, C., Correia, V., Gazimba, V., **Travassos, B.**, et al. (2010). Capturing complex human behaviors in representative sports contexts with a single camera. Medicina, 46(6), 408-414.

Duarte, R., Araújo, D., Fernandes, O., **Travassos, B.**, Folgado, H., Diniz, A. & Davids, K. (2010) Effects of different practice task constraints on fluctuations of player heart rate in small-sided football games. The Open Sport Sciences Journal, 3, 13-15.

Davids, K., Vilar, L., Araújo, D., & **Travassos, B.** (2010). Ball and goal location as constraints on decision-making in team sports. Journal of Science and Medicine in Sport, 12(Sup 2), 92.

Araújo, D., & **Travassos, B.** (2009). Improving Decision-Making Skill in Soccer. In B. Zoudji (Ed.), Football et Recherches (pp. 299-306): Presse Universitaire de Valenciennes.

Visiting research

In the course of the PhD it was also possible to visit other research labs. These visits allowed discussing and developing research with their members:

“Visiting Research” in the “Centre of Human Movement Sciences” of the University of Groningen, The Netherlands, March 2010.

“Visiting Research” in the University of New Brunswick, Canada, under supervision of Professor Tim McGarry, June 2009;

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1. Introduction

Social neurobiological systems, like work organizations or team sports, are characterized by high number of interactions between individuals. The capacity of individuals to constantly adapt their behaviors to instantaneous changes in task conditions is a key issue for developing functional behavior. For that purpose, performers need to improve their decision-making capabilities under performance constraints.

Over the years decision-making in sport has been explored from a cognitive perspective in which behaviors are deemed to be dependent on elaborate cognitive processes that optimize and specify possibilities for action (see Mellers, Schwartz, & Cooke, 1998). In cognitive science the main focus is on the individual and the aim of decision-making analysis is to understand how individuals achieve rationality based on 'standard' rules and goals. Thus, cognitive theories have employed experimental designs and measures to understand how internal mediating structures are responsible for accurate decision-making. Using discrete measures such as verbal reports, response accuracy, response time, reaction time, or eye movements researchers tried to understand individual cognitive processes, somewhat neglecting the conditions of the environment in which a decision emerges (Araújo, Travassos, & Vilar, 2010). This body of work, avoid the fact that decision-making is grounded in the interactions between the individual and the environment, promotes an *organismic asymmetry* or bias towards the individual (e.g., see Davids & Araújo, 2010; Dunwoody, 2006).

In sports science other examples of organismic asymmetry exist. For instance in the analysis of performance in team sports the goal is generally to identify *who* performed an action, and *what* action is performed, neglecting *why* and *how* individuals performed on the basis of interactions between performers (i.e., game environment conditions) or other game constraints such as goal position, ball kinematics, and team strategies. The analysis is grounded in a discrete description of behavior instead of a functional explanation of performance based on the understanding of the continuous changes in individuals and environmental conditions (McGarry, 2009; Travassos, Araújo, Correia, & Esteves, 2010).

In view of the nature of team sports competitive performance, players need to cooperate and coordinate with teammates and compete with opponent players to achieve performance goals. Due to the ongoing dynamic interactions during games, players need to constantly forge and break couplings with other players. More than merely reproduce specific actions at certain moments of performance, players need to constantly adapt their behaviors and create better conditions to play. Through processes of cooperation and opposition between players, the game constitutes itself as a complex system in which adaptive behaviors emerge in a self organized way (Gréhaigne, Bouthier, & David, 1997; McGarry, Anderson, Wallace, Hughes, & Franks, 2002). From this perspective, a more substantial emphasis needs to be placed on understanding how unique performance solutions emerge from ongoing interactions of individuals to satisfy the range of personal, task, and environmental constraints that exist in team games at any moment (Araújo, Davids, & Hristovski, 2006; Newell, 1986).

1.1.An Ecological Dynamics Approach to Decision-Making Behavior

Influenced by ideas of ecological psychology, complexity sciences and biology, ecological dynamics proposes that processes of perception, cognition, decision-making and action emerge through the continuous relationship between individuals and environment (Araújo et al., 2006; Davids, Kingsbury, Bennett, & Handford, 2001; R. Schmidt & Richardson, 2008). The theories of direct perception advocated by Gibson (1979), consider that the relationship between an individual and the performance environment is predicated on the distribution of energy that are rich with information that specifies what is possible or not at a certain moment (Fajen, Riley, & Turvey, 2009; Jacobs & Michaels, 2007). In this view, to achieve functional performance outcomes, individuals need to perceive in order to act and act in order to perceive information for action (Gibson, 1979). The constraint-led approach first introduced by Newell (1986) proposed that perception and action is predicated on the relationship between constraints. Constraints are the variables that compound the system which limit or enable the emergent behavior (Davids, Button, & Bennett, 2008). According to Newell (1986), constraints can be classified in individual, environmental and task. The continuous interaction between individual, environmental and task constraints gives rise to changes in perceptual-motor landscape, i.e., the basis of decision-making for action (McDonald, Oliver, & Newell, 1995).

The decision-making behaviors emerge through a process of self-organization. They result from the interactions between constraints rather than order imposed by one of its elements. Besides this, decision-making regards the convergence to one single action solution from the high number of possibilities for action offered by the environment to each individual (Davids & Araújo, 2010; Kelso, 1995). Possibilities for action are defined by the resultant synergies between an individual's action capabilities and the conditions of a specific performance environment (Fajen & Turvey, 2003). Gibson (1979) used the term 'affordances' to specify the possibilities for action provided by the environment to each individual. Affordance is neither a property of the individual nor of the environment, it is an ecological property established by the goal-directed relationship between the individual and the environment in which he/she acts (Araújo et al., 2006; Turvey & Shaw, 1999). Hence, decision-making is highly dependent on the capability to perceive and explore the surroundings arrays of energy, being operationally defined by the emerging transitions in courses of action (Araújo et al., 2006). In this sense, analyzing patterns of human movement and their transitions, from the perspective of an individual or team is the basis for understanding decision-making. Changes in relevant constraints during performance are also key issues to be studied, since they convey information that individuals use to guide behavior. Measurement and analysis of physical variables that capture the fit between individuals and environment facilitates understanding of the information that constrains decision-making behaviors (Araújo, Davids, Cordovil, Ribeiro, & Fernandes, 2009; Fajen et al., 2009; Turvey & Carello, 1986). Using physical variables that capture the spatio-temporal relations between performers and the environment, such as interpersonal distance, relative angles, relative velocity, and time to contact, it is possible to show how movement is constrained by such information and provide a lawful understanding of human behavior (Araújo et al., 2006; Turvey & Shaw, 1999).

1.2. Informational Based Control for Perception and Action in Sport

Warren (2006) argued that information from the environment constraints patterns of coordination between individuals on the basis of coupling tendencies. From this perspective, the goal-directed interactions between players, from a dyadic to a collective level, result in the emergence of specific patterns of coordination (McGarry et al., 2002).

Previous research on sailing (Araújo et al., 2006), basketball (Araújo et al., 2006), boxing (Hristovski, Davids, Araújo, & Button, 2006), rugby union (Passos et al., 2009) and association football (Duarte et al., 2010; Frencken & Lemmink, 2008) has used measures of movement displacement such as distances, velocities, and angles to capture the regularities of performer-environment or team relations that specify action properties. With the same purpose, other investigations in squash (McGarry, 2006), tennis (Lames, 2006; Palut & Zanone, 2005), basketball (Bourbousson, Sève, & McGarry, 2010a, 2010b) and futsal (Davids, Vilar, Araújo, & Travassos, 2010) have used relative phase analyses. The relative phase is a variable that quantifies and synthesize the spatial-temporal relations between two oscillating agents (Oullier & Kelso, 2009) such as example players or teams geometrical centers. In both cases researchers have revealed that different sports embody properties of self-organizing systems as a result of constant adaptations of players or teams to informational constraints of performance (Araújo & Davids, 2009).

Under specific task constraints, players have their actions linked to relevant perceptual information from other players (e.g., teammates and opponents), events (e.g., players' actions), surfaces (e.g., playing area dimensions) and objects (e.g., the ball or the goal) (Davids et al., 2001). Thus, it implies that relevant constraints such as the relative locations of the players with respect to each other, to the goal, and to the ball, or their positional roles, may be important in shaping the behavioral coordination dynamics that affords decision-making (McGarry, 2009).

However, which variables constrain the emergence of an action like a pass in team sports or how the ever changing conditions of the performance environment guides individuals' behaviors towards successful performance are important issues that remain to be explained. The influence of specific game constraints on the emergence of patterns of coordination between attacker-defender dyads or teams, such as ball dynamics, goal location or changes in the number of players involved in a performance sub-phase, also remains to be understood. A better understanding of the sources of information that constrain the behavior of individuals and teams during performance can contribute to further elucidate the self-organizing nature of team sports. This knowledge might help coaches and performance analysts to improve competitive performance measures used in assessments as well as to develop more representative tasks for practice.

1.3. Aim of the Thesis

The aim of this thesis is to contribute to a better understanding of how effective behaviors of players in a team sports environment are guided by informational constraints. Identifying patterns of coordination of players and teams during performance is a key issue to understand the informational constraints that support decision-making.

In dynamic environments such as team sports, the informational constraints change over time due to dynamics in the relations between individuals and environment. Capturing the emergent patterns of coordination raises a series of issues regarding how information can support the decision and action of individuals and teams. This body of work emphasizes the informational constraints of competitive performance, particularly the interpersonal coordination processes between players' movements, ball trajectory dynamics and goal location. To achieve this goal tools and concepts from ecological psychology and complex systems theory were combined in order to capture the goal-directed relations between players and the performance environment action.

1.4.Structure of the Thesis

The present thesis begins with a meta-analysis quantitative review (Chapter 2) of the effects of expertise on decision-making in sport. In this analysis some key variables that differentiate expert players are identified. Especially clarified is the influence of the research paradigm and stimulus presentation model as moderator variables, on experimental outcomes. This is a hot issue in the study of decision-making that highlights important aspects to account for in the design of experimental tasks. This work reinforces the concept of representative task design to promote a better understanding of decision-making. In the third and the fourth chapters, two studies conducted in a practice task performance setting of futsal are presented. The first investigated the conditions that may afford the performance of a pass by the ball carrier during the game by assessing the interpersonal organization between players. Following study investigates the information-movement coupling that underlies successful and unsuccessful attempts to intercept the trajectory of a passed ball during performance. The methodological approach is based on the examination of the higher order variable time-to-contact between the ball and each defender. In the fifth and the sixth chapters are also described investigations in a practice task of futsal performance setting, this time to identify spatial-temporal patterns of coordination between players and teams. Relative phase analysis was used in order to characterize preferential modes of coordination between players and between teams in relation to informational game constraints such as ball dynamics and goal location.

Together, all the studies contributed to a better understand of how individual players or teams adapted their behaviors to the changing conditions of the performance environment, in order to successfully achieve team performance goals. At the end of this thesis, an overview of the data from all the studies is presented. A general discussion and topics for future research are also provided.

2. The Effect of Expertise in Decision-Making in Sport – A Meta-Analysis

2.1.Abstract

A quantitative review to assess effects of expertise on decision-making in sport was conducted. We considered 106 effect sizes in studies involving 870 participants. Effect sizes were calculated for six dependent variables: verbalized knowledge, eye movement measures, response accuracy, response time, movement accuracy, and movement time. Results revealed that expert performers were more accurate and faster in their responses, verbalized with more detail, and used different visual search patterns than novices. Analysis of moderator variables suggested that expertise effects were more apparent under *in situ* task constraints or when participants performed sporting actions, than when they responded with verbalization or simple micro-movements. Results show that future empirical work on expertise and decision making should use *in situ* task constraints with performers requiring sporting actions to enhance validity of data.

2.2. Introduction

Sport performance requires that athletes adapt and change their behaviors according to the instantaneous demands of the performance environment, when aiming to achieve specific performance goals (Araújo et al., 2006; Hodges, Huys, & Starkes, 2007). Expertise in sport is characterized by the ability to perform functional actions at the right time requiring performers to have excellent perceptual, decision-making and action skills (Williams & Hodges, 2005).

Important research challenges are to understand how expertise constrains decision-making in sport performance and how expertise in decision-making may be acquired and developed in training (Abernethy, Farrow, & Berry, 2003). A study by Abernethy (2008) revealed that to improve performance, experts use a range of different information sources to control their actions and that experts display high levels of adaptive flexibility in their actions compared to non-experts. Generally speaking, it has been observed that skilled performers make more accurate and faster decisions compared to less skilled performers, search for and use different sources of information by employing fewer fixations of longer duration to decide, and display higher levels of flexible motor coordination than novices during performance (see Hodges et al., 2007; Mann, Williams, Ward, & Janelle, 2007).

In summarizing these research findings, it is important to note that analyses of decision making skills have been assessed using a number of different methods and research designs. Guided by emergent theoretical issues on decision-making in sport and aided by technological developments, methods to assess the effects of expertise on decision-making have changed over time. Over the years, stimulus presentation as well the type of movement responses required have changed in a quest to provide more sensitive and reliable measures of expert/novice differences in sport (Hodges et al., 2007). An interesting question concerns how these methodological developments have influenced research outcomes. One of the critical challenges in the study of decision making expertise concerns the ability to design experimental task constraints and conditions that capture the essential characteristics of expertise as expressed in specific sport performance contexts (Ericsson & Ward, 2007; Hodges et al., 2007). This has not proved an easy task due to experimental design issues over information presentation and motor response requirements (Araújo, Davids, & Passos, 2007; Hristovski et al., 2006).

The issue of designing valid experimental task constraints which test decision making skills in sport performers has been informed by the ideas of Brunswik (1956), who argued that only by representing in the laboratory the conditions of a specific behavioral setting for performance will it be possible to discover how individuals perform in those performance contexts (for implications in sport psychology see Pinder, Davids, Renshaw, & Araújo, 2011b). Related to this idea, Van der Kamp, Rivas, Van Doorn, and Savelsbergh (2008) have highlighted the need to consider the link between perception and action in the design of experimental task constraints for studying sport performance. For instance, by considering only perceptual capacities for anticipation and overlooking the movement control requirements on performers in the study of interceptive actions, researchers may be limiting and biasing the capacity of individuals to perform.

In the same line of reasoning, the ubiquitous expert/novice paradigm used in many studies of decision-making in sport, typically falls into the category of 'rational economic modeling', which tends to focus too much on individual capacities and neglects the replication of conditions of the performance environment (Araújo, Davids, & Serpa, 2005; Davids & Araújo, 2010). Cognitive approaches are grounded on the assumption that decision-making processes are dependent on the recall of internal structures that infer the maximal utility of a designated source of information to normatively construed performance (Davids & Araújo, 2010). The problem with this assumption is that in open environments like sports performance contexts, performance conditions as well as performer capabilities change over time. Because of this dynamic context there is no single optimal performance decision that presents the highest rational value for each individual athlete. For instance, in the analysis of 1 vs. 1 sub-phases of Rugby Union, Passos and colleagues (2009) revealed that performers' behaviors were characterized by functional levels of variability that helped them to seek and to discover appropriate conditions to achieve the specific task goals. Additionally, previous investigations of motor behavior have demonstrated that functional variability is key for successful performance outcomes (Davids, Glazier, Araújo, & Bartlett, 2003). This observation signifies that it is difficult to identify a putative optimal decision for a specific performance instance since the emergence of successful decision making depends on the continuous and dynamic interactions between each individual and specific constraints of a performance environment.

To capture these criticisms, an ecological dynamics approach proposed by Araújo and colleagues (2006) has indicated that the relational link between each individual and a performance context provides the basis for understanding decision-making behaviors of individuals in sport. This idea signifies that performers need to be embedded in a performance environment in order to decide and act continuously to achieve specific task goals (B. C. Smith, 1999). For instance, different gaze and movement behaviors of performers have been identified when observed under more artificial conditions (e.g. when performing against video simulations or ball projection machines) than when performing *in situ* (Dicks, Button, & Davids, 2010; Pinder, Renshaw, & Davids, 2009; Renshaw, Oldham, Davids, & Golds, 2007). The latter task constraints constitute natural performance environments such as attempting to dive and save a penalty kick or catch/hit a ball projected by a machine or another individual. These studies demonstrated that the representative design of tasks used in experimental studies can affect the observation of decision making behaviors including expert-novice differences (Araújo et al., 2007; Pinder, Davids, Renshaw, & Araújo, 2011a; Pinder et al., 2011b). From this perspective, a specific performance environment itself is one of the most valid settings for assessing the functionality of expert decisions and actions (Araújo et al., 2007; Davids & Araújo, 2010; Ericsson & Ward, 2007; Hodges et al., 2007).

These ideas from ecological dynamics suggest a need to consider the nature of experimental designs used in previous research on decision making and expertise in sport. In particular there is a need to re-evaluate the specific task constraints under which previous data on expertise in sport and decision making have emerged. The informational constraints of prevalent experimental designs on decision making behaviors (slides, video, *in situ*), the requisite movement responses (verbal reports, button press, performance of sport actions) and the variables used currently to measure expert-novice differences need to be re-assessed to improve understanding of decision-making processes in sport (Ericsson & Ward, 2007). In this respect, a major task is to synthesize existing knowledge accumulated from previous research studies to understand how expertise effects constrain decision-making (Borenstein, Hedges, Higgins, & Rothstein, 2009). Thus, the aims of this study were to: (i) conduct a quantitative review in the form of a meta-analysis to identify the contributing effects of the most common dependent variables used to investigate differences in decision making expertise; and (ii), to evaluate the influence of specific research paradigms and methods of stimulus presentation as potential moderators on these dependent measures.

2.3.Method

2.3.1. Literature search

An electronic literature search was conducted for articles published between January 1995 to March 2010, on the online databases SPORTDiscus with Full Text and ISI Web Knowledge All Databases. Combinations of the following keywords were used: “expert/ise”, “decision making”, “sport”, “performance”, “judgment” and “cognition”, a total of 1287 were analyzed (1072 from Sport Discus, 373 from ISI Web Knowledge excluding 158 that were the same in both databases).

2.3.2. Inclusion criteria

Eligible papers were considered if they were written in English or Spanish: excluded were abstracts from dissertations, book chapters, unpublished data and conference proceedings. Studies needed to employ an expert/non-expert paradigm, use decision making as a key element in the discussion, and present data (means and *SD*, *t* value, exact *p* value, or a simple effect *F* ratio) in order to compute an effect size (Borenstein et al., 2009). A sport performance context was required in the studies. Additionally, only studies that presented information of experience and playing level of participants were considered. To be included in the analysis, participants categorized as expert needed to present more than 10 years of deliberate practice (Ericsson & Ward, 2007). In cases where data on level of experience was missing the studies included in the meta-analysis where those in which expert participants performed in senior high level championships. The first author coded the studies and the fourth author coded a random sample of twenty studies to examine coding reliability (Hagger, 2006). Only 32 papers met the inclusion criteria, generating 106 effect sizes. To estimate the influence of publication bias on the effect size of each dependent variable (i.e., the influence of the studies not considered in calculating the obtained effect sizes), a fail-safe *n* was calculated in order to estimate the number of studies averaging null results (Rosenthal, 1991). A high value of a fail-safe *n* signifies a high level of consistency in the obtained results..

2.3.3. Computation of effect sizes and dependent measures

The effect sizes (ESs) for each identified variable were standardized by calculating the standard differences in means (Borenstein et al., 2009; Hedges & Olkin, 1985). Considering differences in the samples, in the type of measures and the different methods used in each study, a random effect model was used (Hagger, 2006; Hedges & Olkin, 1985).

For analysis of statistical effects, six dependent variables for grouping effect sizes were considered: i) verbalized knowledge (VK) - declarative description that performers used to justify their decisions; ii) eye movement measures (EMM) - different measures that expressed performers' proposed attention to specific informational sources. Here, the number of fixations, fixation duration, fixation order and the number of areas fixated were considered; iii) response accuracy (RA) - frequency of correct decisions based on prior rational evaluations by expert coaches; iv) response time (RT) - the elapsed time between the stimulus presentation and the beginning of a response; v) movement accuracy (MA) - frequency of functional behaviors performed to successfully achieve specific performance goals; vi) movement time (MT) - the time duration required to perform a specific movement to achieve performance goals. Dependent variables such as response consistency, procedural knowledge and brain activity were also identified but with an insufficient number of studies to be included in this meta-analysis.

The heterogeneity between ESs was analyzed by applying a Q test. The Q value represents the total of variance among all the ESs. A significant Q value reveals the level of heterogeneity in a data set. A non-significant Q value reveals similarity of the effect across studies, i.e., homogeneity.

Also, in order to test the moderator variables, $Q_{(bet)}$ values were calculated. A significant effect indicated that the moderator variable contributed to the variance among ESs (Borenstein et al., 2009; Higgins, Thompson, Deeks, & Altman, 2003). The entire data set was transformed in Comprehensive Meta-Analysis software package, 2008 (BioStat, Englewood, New Jersey).

2.3.4. Moderating variables

To evaluate the extent to which the effects of expertise in decision-making were influenced by different conditions of research studies, two moderator variables were examined. We assessed the merits of "research paradigm" and "type of stimulus presentation" as potential moderating variables. Three conditions were considered for research paradigm: i) *verbal reports*, ii) *button pressing*, iii) *performance of sport actions*. For stimulus presentation, three conditions were also considered: i) *slide images*, ii) *video presentations*, iii) *in situ* (defined as the information present during actual performance of relevant sport actions in specific performance contexts such as a participant diving to save a penalty kick in football or hit a cricket ball with a bat).

2.4.Results

2.4.1. General analysis

After eliminating the studies that did not achieve the inclusion criteria, 106 effect sizes were considered, involving 870 participants, of which 47,13% (N=410) were considered as expert and 52.87% (N=460) were considered as non-expert. The reported effect sizes were thereby categorized. Each dependent variable was analyzed independently and significant results in heterogeneity test for Reaction accuracy and Reaction time variables ($Q_{(t)}$=177.83, $p<.001$ and $Q_{(t)}$=52.99, $p<.001$, respectively) were observed.

Verbalized Knowledge (VK). The 12 effect sizes of VK revealed a high significant effect size ES= 1.31 (95% CI 0.99-1.63), with Z=8.16, $p<.001$. The Q-test for heterogeneity revealed non-significant values $Q_{(t)}(11) = 4.13$, $p > .05$ i.e., homogeneity. The fail-safe *n* was 197, signifying that approximately 200 studies averaging null results would be needed to modify the significance of the current effect size for the VK variable.

No studies assessing verbal report measures of athletes were found to use a *performance of sport actions* condition for the "research paradigm" moderator variable, nor an *in situ* condition for the "stimulus presentation" moderator variable The overall estimate of the effect size between groups (Q_{bet}) was calculated with statistically non-significant outcomes ($p>.05$). This evaluation indicated that none of the proposed moderating variables were moderating VK (see table 2.1.).

Table 2. 1. - Results of expertise difference for Verbal Knowledge (VK) and Eye movement measures (EMM)

VK	**N**	**ES**	**95% CI**		**Q**	**df (Q)**	**P-value**
Total	12	1.31	1.00	1.63	4.13	11	0.97
Research Paradigm							
Verbal reports	4	1.30	0.83	1.77	1.28	3	0.73
Button press	8	1.32	0.90	1.75	2.84	7	0.90
Sport Performance	-	-	-	-	-	-	-
Total between					0.00	1	0.95
Stimulus Presentation							
Slide	4	1.22	0.77	1.66	0.64	3	0.89
Video	8	1.42	0.97	1.87	3.09	7	0.88
In situ	-	-	-	-	-	-	-
Total between					0.39	1	0.53
EMM	**N**	**ES**	**95% CI**		**Q**	**df (Q)**	**P-value**
Total	22	1.18	0.97	1.39	20.55	21	0.49
Research Paradigm							
Verbal reports	-	-	-	-	-	-	-
Button press	6	1.35	0.91	1.78	7.44	5	0.19
Sport Performance	16	1.13	0.88	1.37	12.38	15	0.65
Total between					0.73	1	0.39
Stimulus Presentation							
Slide	1	1.22	0.42	2.03	9.36	0	1
Video	14	1.16	0.92	1.41	14.45	13	0.34
In situ	7	1.24	0.75	1.73	6.01	6	0.42
Total between					0.08	2	0.96

Eye Movement Measures (EMM). The 22 effect sizes in which EMM were identified revealed a high significant effect size ES= 1.18 (95% CI 0.97-1.39), with Z=10.89, $p<.001$. The Q-test for heterogeneity revealed non-significant values $Q_{(t)}(21) = 20.54$, $p > .05$ i.e., homogeneity. The fail-safe *n* was 691, signifying that approximately 700 studies averaging null results would be needed to modify the significance of the current effect size for the EMM variable.

For "research paradigm" the *verbal reports* condition was not found in any study using EMM. The overall estimate of the effect size between group (Q_{bet}) was calculated with non-significant results (p>.05). Therefore none of the proposed moderator variables were deemed to be influences on EMM (see table 2.1.).

Response Accuracy (RA). The 42 effect sizes in which RA was identified revealed a highly significant effect size ES= 1.64 (95% CI 1.31-1.96), with Z=9.95, p<.001. This was the dependent variable that presented the highest number of measurements from the whole sample of studies analyzed. The Q-test for heterogeneity revealed significant values $Q_{(t)}(41) = 177.83$, $p < .001$, i.e., heterogeneity (see table 2). The fail-safe *n* was 4.293, signifying that approximately 4.300 studies averaging null results would be needed to modify the significance of the current effect size for the RA variable.

The overall estimate of the effect size between groups was calculated for each of the moderating variables with significant results for "research paradigm" Q_{bet} (2)=6.56, p=.05 and "stimulus presentation" Q_{bet} (2)=8.92, p<.05. This finding indicates that the proposed moderating variables were really moderating for response accuracy (see table 2). Moreover, calculation of the Q_{bet} revealed homogeneity just for *in situ* conditions in the moderating variable "stimulus presentation" $Q(7) = 12.94$, $p > .05$. The other conditions revealed heterogeneity in the results (see table 2.2.).

Response time (RT). The 22 effect sizes in which RT were identified revealed a highly significant effect size ES= 1.30 (95% CI 1.13-1.48), with Z=9.61, p<.001. The Q-test for heterogeneity revealed significant values $Q_{(t)}(21) = 52.99$, $p < .001$, i.e., heterogeneity. The fail-safe *n* was 1.302, signifying that approximately 1.300 studies averaging null results would be needed to modify the significance of the current effect size for the RT variable.

The overall estimate of the effect size between groups was calculated for each of the moderating variables with significant results for "research paradigm" $Q_{bet}(1)$=39.47, p<.001 but not for "stimulus presentation" $Q_{bet}(2)=1.13$, $p>.05$. Thus, "research paradigm" is a moderator for response time, contrary to "stimulus presentation" (see table 2.2.). However, as observed in table 2 *verbal report* measures were observed in only one study and presented a huge effect size. This result may have biased the analysis of "research paradigm" as moderator variable. The Q-test for heterogeneity applied to the "research paradigm" moderating variable revealed homogeneity for *performance of sport actions* condition with $Q(7) = 12.94$, $p > .05$ and as expected for *verbal reports* $Q(0) = 0$, $p = 1$. The Q-test for heterogeneity applied to "stimulus presentation" revealed homogeneity for *in situ* conditions with $Q(1) = 0.05$, $p > .05$. The other conditions revealed significant results for heterogeneity (see table 2.2.).

Table 2. 2. - Results of expertise difference for Response accuracy (RA) and Response time (RT)

RA	**N**	**ES**	**95% CI**		**Q**	**df (Q)**	**P-value**
Total	42	1.63	1.31	1.96	177.83	41	0.00
Research Paradigm							
Verbal reports	3	1.74	0.64	2.85	8.59	2	0.01
Button press	28	1.41	1.00	1.81	136.66	27	0.00
Sport Performance	11	2.19	1.68	2.70	19.01	10	0.06
Total between					6.56	2	0.05
Stimulus Presentation							
Slide	5	1.92	0.99	2.85	21.01	4	0.00
Video	29	1.38	1.00	1.75	126.76	28	0.00
In situ	8	2.59	1.87	3.32	12.94	7	0.07
Total between					8.92	2	0.01
RT	**N**	**ES**	**95% CI**		**Q**	**df (Q)**	**P-value**
Total	22	1.30	1.13	1.48	52.99	21	0.00
Research Paradigm							
Verbal reports	1	4.24	2.66	5.83	0	0	1
Button press	14	1.36	1.02	1.71	33.37	13	0.00
Sport Performance	7	1.29	0.95	1.62	6.09	6	0.41
Total between					12.89	2	0.00
Stimulus Presentation							
Slide	8	1.45	0.89	2.01	26.1	7	0.00
Video	12	1.39	1.02	1.75	25.7	11	0.00
In situ	2	1.76	0.80	2.72	0.05	1	0.81
Total between					0.52	2	0.77

Movement Accuracy (MA). The 5 effect sizes in which MA was identified revealed a highly significant effect size ES= 3.47 (95% CI 2.23-4.71), with Z=5.48, $p<.001$. The Q-test for heterogeneity revealed non-significant values $Q_{(t)}(4) = 9.01$, $p > .05$, i.e., homogeneity. The fail-safe *n* was 87, signifying that approximately 100 studies averaging null results would be needed to modify the significance of the current effect size for the MA variable. All of the studies measured participants' *sport actions* behaviors in *in situ* conditions. Thus, subsequent analyses of effect of moderating variables were not conducted.

Movement Time (MT). The 3 effect sizes in which MT was identified revealed a high significant effect size ES= 1.37 (95% CI 0.82-1.91), with Z=4.89, $p<.001$. The Q-test for heterogeneity revealed non-significant values $Q_{(t)}(2) = 0.70$, $p > .05$, i.e., homogeneity. The fail-safe *n* was 16, signifying that approximately 20 studies averaging null results would be needed to modify the significance of the current effect size for MT variable. All of the studies measured participants' *sport actions* behaviors in *in situ* conditions. Thus, subsequent analyses of effect of moderating variables were not conducted.

2.5.Discussion

In this study we undertook a quantitative review of the literature to identify the effects of expertise on the most prevalent variables used to measure decision-making in studies of sport performance. The influence of key prevalent research conditions was also tested.

Analysis of dependent variables confirmed expectations in the reported literature that expert performers were more accurate and faster in making their decisions than less skilled performers. It was also observed that expert performers verbalized in greater detail the information used to justify their decision making. Significant differences between expert and non-expert performers were observed for visual search patterns during decision making, with the former undertaking fewer fixations of longer duration to fewer display areas than non-expert ones. The order of fixations also seemed to be different, results which are in agreement with previous research (Hodges et al., 2007; Mann et al., 2007).

According to Ericsson and Ward (2007) different task constraints allow different performance approaches. They argued that sports performance is closely related to the experimental conditions in which it occurred. In the analysis of expertise, it is particularly important to measure performance under controlled conditions which allow the capture of differences in decision making and performance on representative tasks. We examined the influence of “research paradigm” and “stimulus presentation” methods to distinguish expertise in decision making behaviors in sport. Our results revealed no moderating effect of both “research paradigm” and type of “stimulus presentation” for the assessment of verbalized knowledge. These findings indicate that the information that experts verbally report is independent of the type of stimulus or the research paradigm used. Also, no studies were found for verbalized knowledge using *performance of sport actions* measures or *in situ* conditions. This is an interesting observation suggesting that the capacity to produce verbal reports is quite distinct from the capacity to organize actions during performance (i.e., tactical skills) (Araújo et al., 2010).

The analysis of visual search patterns also revealed no moderating effect of both “research paradigm” and “stimulus presentation” conditions. These findings indicate that visual search patterns in decision making are independent of the type of stimulus or the research paradigm used to study them. Consistency of effect sizes were also observed across the studies in our sample, i.e., homogeneity for the obtained main effect. This finding suggests that the magnitude of the effect between novices and experts is similar for all visual search measures. These results contradict data reported by Mann and colleagues (2007) in the study of perceptual-cognitive expertise in which the number of fixations, fixation durations and quiet eye measures revealed heterogeneity in their results. The differences between the two studies can be justified by the fact that Mann and colleagues evaluated perceptual movement expertise by considering a multitude of research protocols (anticipation, decision-making, recall, task performance and others) and in this study we just evaluated the effect of expertise on decision-making behaviors. It is interesting to note that despite reporting different eye movement measures in our analysis, consistency / homogeneity in the results were observed. These differences in results highlights that the task goal used in a research study can act as a powerful constraint on the emergent perceptual-motor behaviors of participants during performance. In this way, the results of studies incorporating the performance of perceptual-motor behaviors seem more consistent when analyzing particular types of behavioral processes, such as decision making.

Response accuracy revealed moderating effect of both "research paradigm" and "stimulus presentation". However, variability of effect sizes across considered studies was observed, i.e., heterogeneity for the obtained main effect. Differences in the effect of moderating variables compared to the previous variables (i.e., verbalized knowledge and eye movement measures) can be explained by the fact that when the outcome of performance is measured the type of stimulus and the way in which performers expressed their expertise are key aspects to consider in research (Ericsson & Ward, 2007). These results highlighted concerns to preserve the information-action relationship in the design of experiments on decision making and expertise in sport (Araújo et al., 2006; Davids & Araújo, 2010; Ericsson & Ward, 2007; Hodges et al., 2007; Pinder et al., 2011a, 2011b; Van der Kamp et al., 2008). This issue is reinforced by the fact that *performance of sport actions* conditions in the "research paradigm" variable and in *situ* conditions for "stimulus presentation" presented high values for effect size and were the unique experimental conditions that displayed homogeneity, i.e., consistency under their effects.

Reaction Time analysis also revealed moderating effects of research paradigm but not for stimulus presentation. Variability of effect sizes across considered studies was observed, i.e., heterogeneity for the obtained main effect. However, despite these findings, it was observed that the main differences observed were between *verbal reports* and the other two conditions (*button pressing* and *performance of sport actions*). This result may have been influenced by the low number of studies analyzed for declarative knowledge (i.e., just one study). Thus, avoiding *verbal reports* and considering only *button pressing* and *performance of sport actions* conditions, no moderating effect was observed. According to these results it could be argued that no moderating effects exist for reaction time. The analysis of each condition for each moderator variable also revealed that *performance of sport actions* conditions in the "research paradigm" variable and in *situ* conditions for "stimulus presentation" were the unique experimental conditions that displayed homogeneity in their effects, i.e., consistency on effect sizes across considered studies.

Such observations for reaction accuracy and reaction time highlight that expertise effects were more consistently observed in actual performance conditions when participants performed sporting actions in studies of decision making. Expertise effects reported were not as clear under laboratory task constraints when processes of perception and action were used in ways that differed from the way they are used in actual performance settings. For instance, the magnitude and the consistency in results between experts and novices change if performers were evaluated using a *video presentation* and a *button press* response or using an *in situ* condition with *sport actions* behavior. Under the latter conditions of research the results seemed to be more consistent between studies and with higher effect size values reported. These findings support the proposal of Van der Kamp and colleagues (2008) who revisited the seminal findings of Milner and Goodale (1995) to explain that decoupling processes of perception and action may change the complementary relations between distinct areas of the cortex used for perceiving objects (ventral stream) and for perceiving information for action (dorsal stream). Designing task constraints which decouple processes of perception and action (e.g., using verbal reports or button press actions to express decision making) may inadvertently emphasize the use of perception for object identification or to judge a possibility for action, rather than cortical streams which support perception for sport action. This type of design feature has consequences for studying decision making behaviors of performers in dynamic action contexts like sport. This issue has also been raised by ecological psychologists emphasizing the need to understand human behaviors based on the interactions between individuals and their performance environment (Araújo et al., 2010; Davids & Araujo, 2010; Dicks et al., 2010; Turvey, 2007; Warren, 2006).

In analyses of movement accuracy and movement time variables all of the studies in the sample measured participants' *sport actions* in *in situ* conditions. Thus, contrary to the outcomes for other dependent variables, the effects of moderating variables were not analyzed. The observed results for movement accuracy and movement time revealed consistency in the data, i.e., homogeneity. In addition, analysis of movement accuracy also revealed the highest overall effect size in comparison with the other dependent variables.

Despite the relatively small number of studies used in the meta-analysis, the data highlighted some important trends in the study of expertise effects in decision making in sport. The goal directed behaviors measured with the variables movement accuracy and movement time required participants to make perceptual judgments under specific performance environments allows the emergence of unrestricted functional responses. The behavior of individuals changed the performance conditions and also the informational constraints of the performance environment in a cyclical way (Dicks et al., 2010). With changes in research design and measured variables from laboratory-based to more representative performance settings, individuals assumed a more active role in relation to the environment instead of independence in relation to external objects or events (Van der Kamp et al., 2008). This type of experimental task constraints make it possible to measure how individuals change their behaviors according to emerging environmental demands to achieve a task goal (Araújo et al., 2006; Davids et al., 2001; Ericsson & Ward, 2007; Hodges et al., 2007). The results on movement accuracy and movement time revealed a small fail-safe *n* (approximately 100 and 20, respectively) which means that a low number of studies are sufficient to average null results. This is a limitation of our research. However, we argue that this low number of studies using movement accuracy and movement time is consequence of a recent emphasis on these variables to assess decision-making behavior and not a bias of publication promoted by our literature search. Future research is needed to broaden the analysis of decision-making in sport using movement accuracy and movement time.

To summarize, in line with previous research this study revealed that expert performers present more accurate (higher response accuracy, movement accuracy and lower movement time) and faster decisions (lower response time) and verbalized more information than non-expert performers. Based on eye movement measures expert performers revealed also different strategies searching for information in comparison with non-expert ones. However, it was also observed that the dependent variable that present high number of studies was response accuracy and the dependent variables that present lower number of studies was movement time and movement accuracy. In the future more research based on movement accuracy and movement time is needed to test the consistency of these variables.

It was observed that verbalized knowledge and eye movement measures were consistent in the results and not presented any effect of the moderating variables. This means that the captured behavior was not influenced by the type of research or the stimulus presented. Hence, using only verbal reports or eye movement measures to study decision-making processes researchers can lose unique contextual performance solutions by neglecting the individual process of adaptation of performers to performance conditions. Based on homogeneity results of variables related with behavior (reaction accuracy, reaction time, movement accuracy and movement time) on *performance of sport actions* and on *in situ* conditions it was suggested that the effect of expertise was well captured. It was justified by the fact that when it was maintained the link between specific game information and sportive actions, expertise effects were more consistent. It will be important concerns for future research on decision-making by improving research designs to maintain the conditions of behavior setting for performance and the possibilities for action as in actual performance environment. At the end, we observed two studies that used brain activity measures to test the effect of expertise in decision making in sport context. An interesting issue for the future could be the understanding of the relationship between performance measures and brain activity measures that characterize the effect of expertise in decision-making.

2.6.References

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3. How information from emergent interpersonal interactions of performers regulates passing actions in team ball sports

3.1.Abstract

Considering team ball sports as a complex biological system, we investigated how interpersonal interactions regulated affordances for passing actions during competitive performance. For this purpose, 24 successful passing actions of 15 skilled male performers (mean age=23.25, s=1.96 yrs) were video recorded and digitized during futsal match practice. After previous research, we identified successful interpersonal interactions by plotting values of interpersonal distances between them during performance. Results showed that interpersonal distances between performers converged to a functional spatial configuration (i.e., a decrease in variability of interpersonal distances across trials) affording the emergence of a pass in futsal. The strength of couplings between interpersonal distance values during performance sustained local interaction rules for emergent perception and actions in team ball sports as complex social systems.

3.2. Introduction

As in other complex biological systems (R. C. Schmidt, Christianson, Carello, & Reuben, 1994; Theraulaz, Gautrais, Camazine, & Deneubourg, 2003), the capacity of individuals to constantly adapt their behaviors to environmental conditions is key to effective performance in team ball sports. Ecological dynamics has proposed that the relationship between individuals and environments should form the relevant scale of analysis in psychological research on perception, decision making and action (Araújo et al., 2006; Fajen et al., 2009). The interactions and adaptations of individuals to the environment are based on the specific informational variables which specify pathways to achieve specific performance goals (Fajen et al., 2009; Warren, 2006). This line of reasoning conceptualizes that team ball sports performance are guided by simple local interaction rules on the basis of coordination patterns that emerge between system agents: the attackers and defenders in opposing teams (Passos et al., 2011). In order to understand the local rules that sustain coordination patterns in team sports there is a need to study the interactions between performers that afford the emergence of functional actions to achieve specific task goals like passing the ball successfully or shooting at goal (see Araújo et al., 2006).

3.2.1. How do individuals regulate actions in complex social systems?

In ecological dynamics, the perception of possibilities for action, i.e., affordances, is a continuous process of individuals detecting information from their interactions with their surroundings to support goal-directed actions (Araújo et al., 2006). That is, physical conditions of the environment provide opportunities for individuals to act in relation to their intentions. The implication is that performers need to continuously couple their actions to relevant perceptual information sources provided by the positioning and movements of other performers (e.g., teammates and opponents) (Davids et al., 2001). These relationships are dynamic and nonstationary, being defined by a complementary fit between the constraints of individual performer and the physics of the environment (Warren, 2006). As argued by Fajen, Riley and Turvey (2009), performers act sustained by local information generated by changes in the positioning of other performers and vice-versa to achieve specific performance goals in a direct way.

In social complex systems involving interactions between individuals, Marsh and colleagues (2006) have advocated that possibilities for action are sustained by the couplings formed between individuals. For example, such couplings have been identified in empirical work on between-person movement coordination tendencies (R. Schmidt & Richardson, 2008; R. C. Schmidt et al., 1994; R. C. Schmidt, O'Brien, & Sysko, 1999). To investigate such couplings, key physical relational measures, that synthesize the interpersonal interactions formed to undertake specific tasks in social coordination, have been developed (e.g., relative phase of the frequency of oscillations of individual movements). Dynamical changes in the interpersonal interactions have been observed by manipulation of informational and physical constraints. This design has allowed demonstrating how an actor’s behavior were constrained by the actions of other individuals involved in the performance context, shaped by the dynamical changes in the informational couplings between them (Marsh, Richardson, & Schmidt, 2009).

3.2.2. What information sources constrain action possibilities in team ball sports?

As in other social contexts, possibilities for action in team ball sports depend on the social interactions and relations that emerge between performers. For example, to perform a successful pass to a teammate, an individual in possession of the ball (denoted throughout this paper as a ball carrier) needs to detect a gap between opponents that affords an opportunity to make a pass without interception (Fajen et al., 2009). However, this is extremely challenging since gaps in team defensive formations can appear and disappear instantaneously, as defenders continuously adjust their positions, and constrain the possibilities for an attacker’s passing actions over time. To deal with the pattern forming dynamics of defensive systems in team ball sports, the ball carrier and other teammates try to create space to move the ball closer towards the goal or to keep possession of the ball. To counter these cooperative tendencies in attacking sub-systems, defending team players cooperate by coupling their movements with the trajectory of the ball and other teammates in order to deny space for attackers (Travassos, Araújo, Vilar, & McGarry, In press).

Previous research has demonstrated that interpersonal distance between performers and immediate teammates or opponents is a reliable social system variable to investigate interpersonal coordination tendencies during performance (e.g., Araújo et al., 2006; Passos et al., 2011). For example, in a 1v1 sub-phase of rugby union Passos et al. (2008) verified that the interpersonal distance value between an attacker with the ball and an opposing defender became critical at less than 4m. Their findings signified that, below this distance value, the confluence of interpersonal organization tendencies converged to a kind of stable state irreversibly constraining both performers' affordances (Passos et al., 2009). Furthermore, in a 4 v 2+2 sub-phase of rugby union, data suggested a tendency for functional interpersonal distance values between performers to emerge during practice (Passos et al., 2011). These findings in different sub-phases of team ball sports revealed how performance behaviors emerge on the basis of local interaction rules sustained by critical values of key variables like interpersonal distance between individual players to achieve their goals. To our knowledge, there have been no attempts to examine the spatial conditions that afford the emergence of functional passing actions in team ball sports as social systems. Research is needed to investigate the spatial nature of the interactions between performers under different task constraints and in different team sports that specify action possibilities such as passing a ball to a teammate.

In this study we aimed to investigate how interpersonal coordination tendencies in futsal regulate passing actions during competitive performance. To achieve our aim, we recorded in a futsal practice task performers' displacements and computed the interpersonal distance values between a ball carrier and a teammate who received the ball as well as the interpersonal distances between the ball carrier and two immediate defenders specifying the spatial window through which the passing trajectory needed to be performed. In successful passing actions, we expected to observe a convergence in distances between a ball carrier and immediate opponents towards functional values that afforded a pass. In addition, it was predicted that there would be a convergence in values of interpersonal distances to the moment that a pass was made, as interactions are regulated by coupling tendencies between performers.

3.3.Method

3.3.1. Participants

Fifteen, male senior players (mean value =23.25, *s*=1.96 years) of the Portuguese National Universities Futsal squad were divided into three equal teams to participate in the study. All players gave informed consent to act as participants, and all experimental procedures were approved by the local university ethics committee, and conducted in agreement with the guidelines of the American Psychological Association (2003).

3.3.2. Task

As a task vehicle to examine local interaction rules in team ball sports, a series of futsal practice games was implemented with participants. Futsal is a five-a-side, indoor Association football game with specific rules defined by Féderation International Football Association (FIFA). The experimental task comprised nine Futsal practice games of five minutes duration each. Each team competed against the other teams on three separate occasions. For either team the task goal was to win each match by scoring more goals than the opposing team according to the laws of the game.

3.3.3. Data collection

Player performance during the Futsal practice games was video recorded at 25Hz using a digital camera placed at an angle 45º to the mid-pitch line, in a superior plane, to capture the movements of all players and the ball. Digital video film clips of attacking phase play, performed in the attacking half of the pitch of the team in possession of the ball, were recorded. Phases of play in which passes were performed *into* the defensive organization (i.e., the surface area shaped by the defensive players' positioning) or which crossed it, were all selected for analysis.

Twenty four passing moves were identified as successful. Successful passes were considered when targeted teammate receives the ball. In order to examine the local interaction rules that guided the performance of passing actions in the team ball sport of futsal as a complex social system, the behaviors of four key individuals were considered: (i) the performer with the ball (ball carrier), (ii) the targeted teammate who was intended to receive the ball (ball receiver), (iii) the nearest opponent to the ball carrier, and (iv), the second nearest opponent to the ball carrier (see Figure 1). Data on the movement displacement trajectories of the selected performers were digitized with TACTO software in slow motion (see procedures in Duarte et al., 2010; Fernandes & Malta, 2007). The obtained movement coordinates were transformed into real coordinates using the direct linear transformation method (2D-DLT) and filtered with a Butterworth low pass filter (6Hz) (Winter, 2005). All data were computed in MATLAB software (R2008a, MathWorks, USA).

3.3.4. Measuring interpersonal distance during passing actions

In order to measure how interpersonal distance between performers constrained the emergence of a passing action to a teammate, the distances between all performers were recorded from the moment at which a teammate performed the pass to the ball carrier, to the moment of pass initiation by the ball carrier. Interpersonal distance values were measured between the: (i) ball carrier and ball receiver; (ii) ball carrier and the 1st defender (nearest defender), ball carrier and the 2nd defender (second nearest defender) and, between the two defenders (see Figure 3.1).

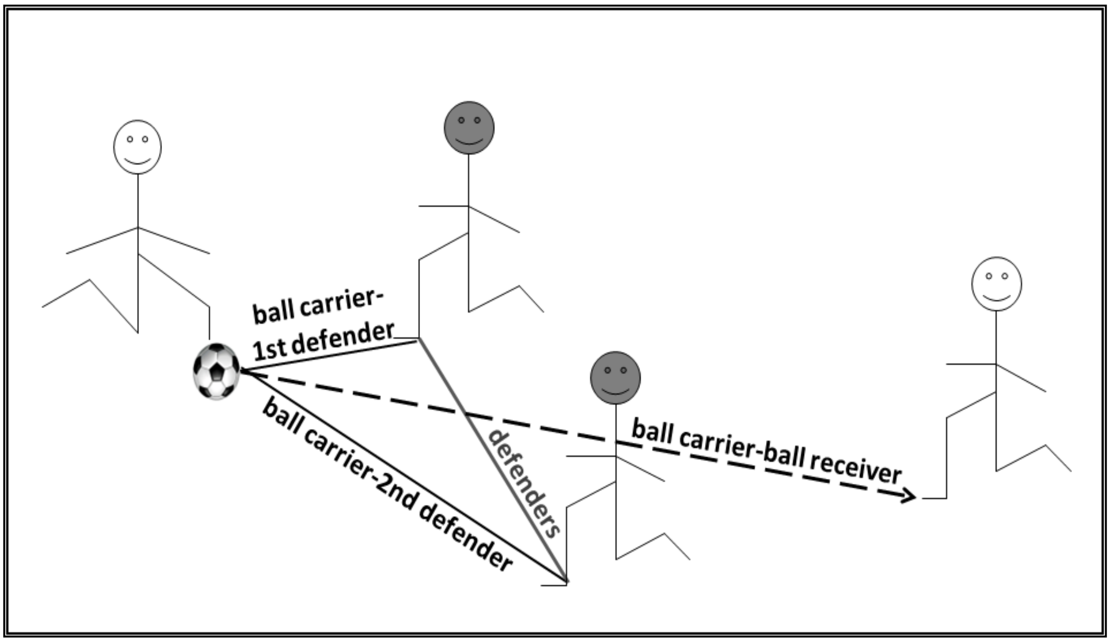

Figure 3. 1 - Representation of a passing action at the moment of pass initiation. The white symbols represent the attackers, the grey symbols represent the defenders. The black thin lines represent the interpersonal distance values between the ball carrier and each of the defenders. The grey line represents the interpersonal distance values between both defenders and the dashed black line, the interpersonal distance between the ball carrier and ball receiver.

For statistical comparison purposes, each trial was normalized to the total time taken to perform the trial. The value of 0% corresponds to the moment at which a teammate performed the pass to the ball carrier. The value of 100% was the moment of pass initiation by the ball carrier. Interpersonal distances of all participants were calculated for each trial. The mean value of each interpersonal distance was measured over time for all the trials. Variability around the mean distribution across trials was calculated using standard deviation (SD) and percentage of coefficient of variation (%CV) measures (Mullineaux, Bartlett, & Bennett, 2001; Stergiou, 2004).

3.3.5. Measuring coupling tendencies between performers

To measure coordination tendencies in the interpersonal distance values between performers, we used running correlations with a 5-point window size which corresponds to 20% of the time in each performance trial. Running correlations allowed us to measure the coupling tendencies between participants, reflected by the pairing of interpersonal distance values during each trial (Stergiou, 2004). Running correlations (r) oscillate between values of 1 and -1, with values of r close to 1 indicating a high positive coupling between values of interpersonal distances at any instant during performance. That is, when one distance value increases, the other distance value also proportionally increases. Values of r close to -1 indicate a high level of negative coupling. That is, when one distance value increases, the other distance value decreases proportionally. Values of r close to 0 reflect a lack of coupling tendencies in the interpersonal distance values of performers.

3.3.6. Reliability

Reliability of data were assessed using technical error of measurement (TEM) and coefficient of reliability (R) statistics, respectively (Goto & Mascie-Taylor, 2007). The intra-TEM measure yielded values of 0.137 meters (0.23%) indicating a good level of reliability (R=.984) in the methods for estimating the positioning of performers.

3.4.Results

3.4.1. Analysis of interpersonal distances values between performers

Analysis of the variability of interpersonal distance values across trials revealed a decrease in the magnitude of SD and %CV values from the moment at which the teammate passed to the ball carrier (0% of time), to the moment of pass initiation by the ball carrier (100% of time). A decrease in the %CV was observed for interpersonal distance values between: (i) the ball carrier and 1st defender (35.80% to 26.18%); (ii) the ball carrier and 2nd defender (31.14% to 23.18%); and (ii) between the two defenders (30.24% to 19.34%). However, in our analysis of interpersonal distance values between the ball carrier and ball receiver, we observed an increase in the magnitude of variability (42% to 47.16%) (see Figure 3.2).

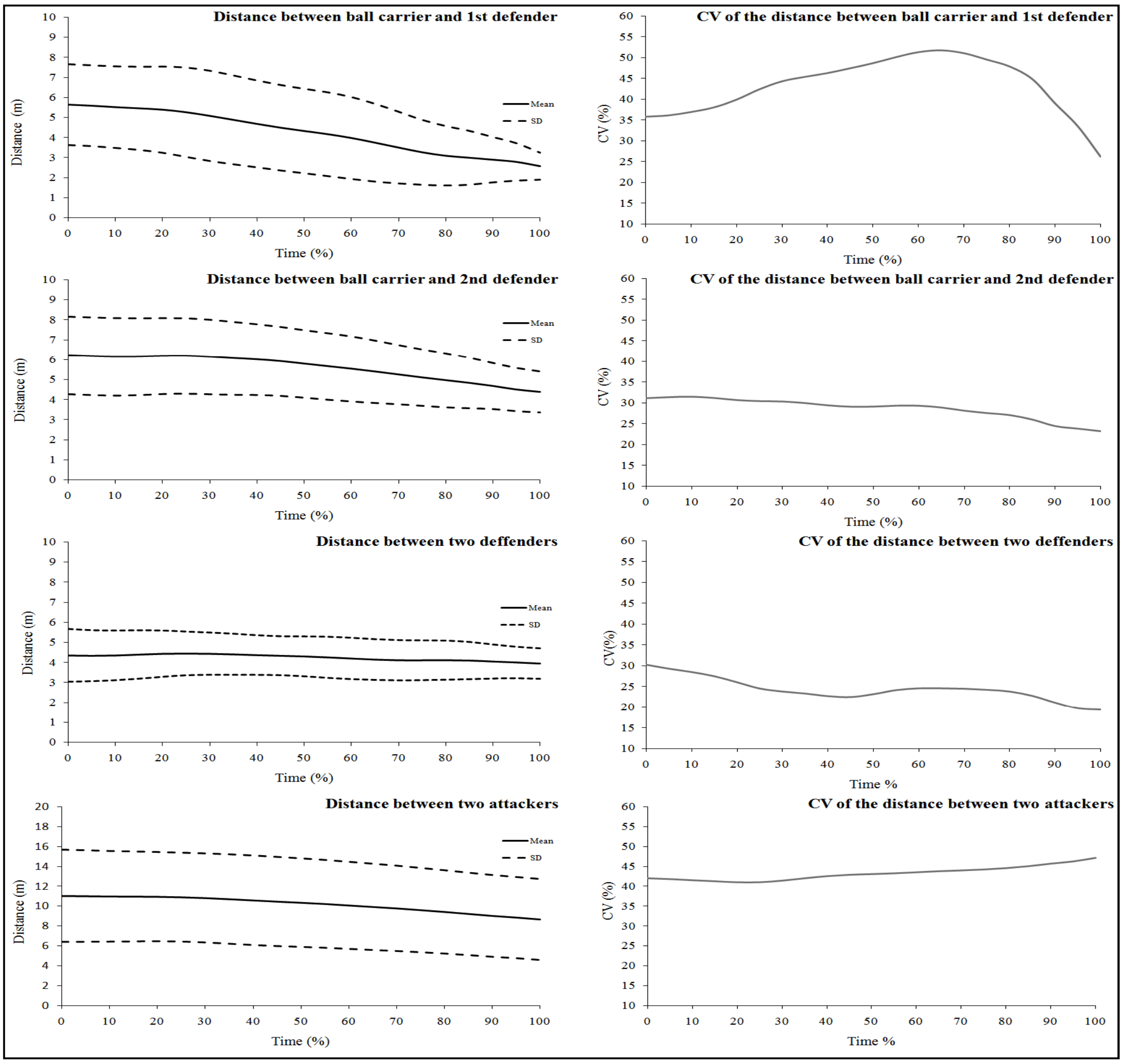

Figure 3. 2 - Interpersonal distance values in passing actions from the moment at which a teammate performs the pass to the ball carrier to the moment of pass initiation by the ball carrier. Left panels – Mean and SD for interpersonal distance data. Right panels – Coefficient of variation for interpersonal distance data (%CV)

3.4.2. Analysis of coupling tendencies reflected in interpersonal distance values

Results from the analysis of coupling tendencies between interpersonal distance values of performers revealed a variability of inter-relations over time. Figure 3.3 displays running correlations results for three trials for the interpersonal distance pairings between the participants. Despite the observed variability over trials, for the different pairs of interpersonal distances, it was observed that by the end of each trial values of *r* converged towards 1. This statistical finding implies that, during each trial, the distances between performers increased and decreased in different proportions. However, at the end of each trial the interpersonal distances relations between performers converged to a positive coupling, i.e., both interpersonal distances increased/decreased at the same rate.

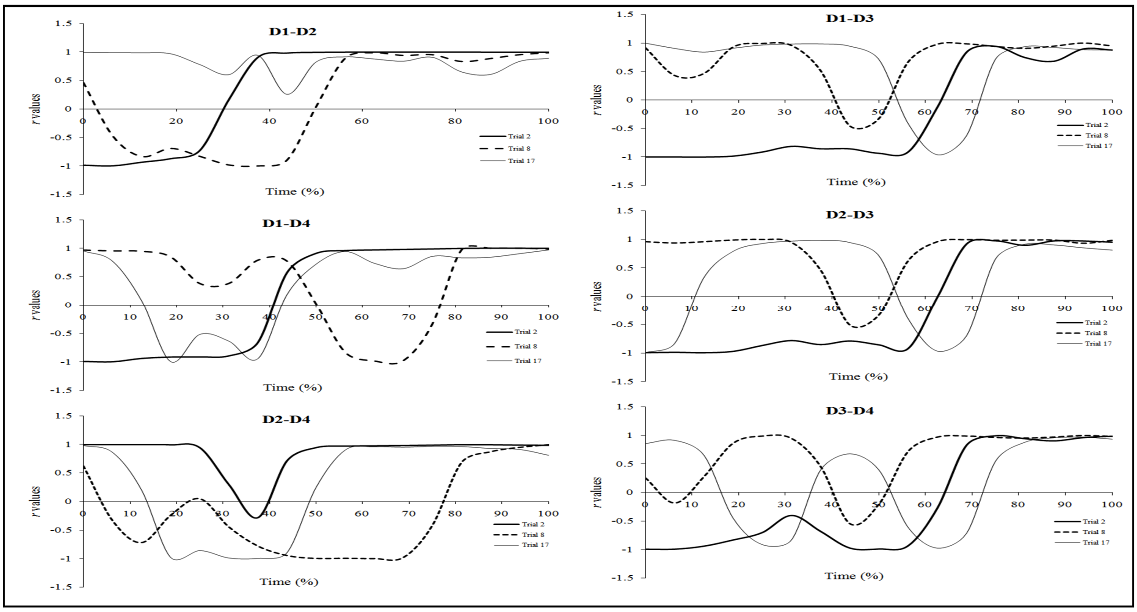

Figure 3. 3 - Exemplar trials of running correlations for each interpersonal distance pair. D1 = distance between ball carrier and 1st defender; D2 = distance between ball carrier and 2nd defender; D3 = distance between defenders; D4 = distance between attackers.

Due to similarities in the structure of the running correlations, a landscape of the total frequencies of the running correlations for each interpersonal distance pair was developed. Figure 3.4 presents the landscape of the running correlation percentage of frequencies. Each line corresponds to each interpersonal distance pair. Results revealed a tendency for a positive coupling ($r = 1$) for all interpersonal distances pairs with a frequency close to 50%. These results reflected the coupling tendencies between interpersonal distances at the end of the trials in which, despite initial variability, in the interpersonal distances relations between performers, a convergence towards positive couplings emerged.

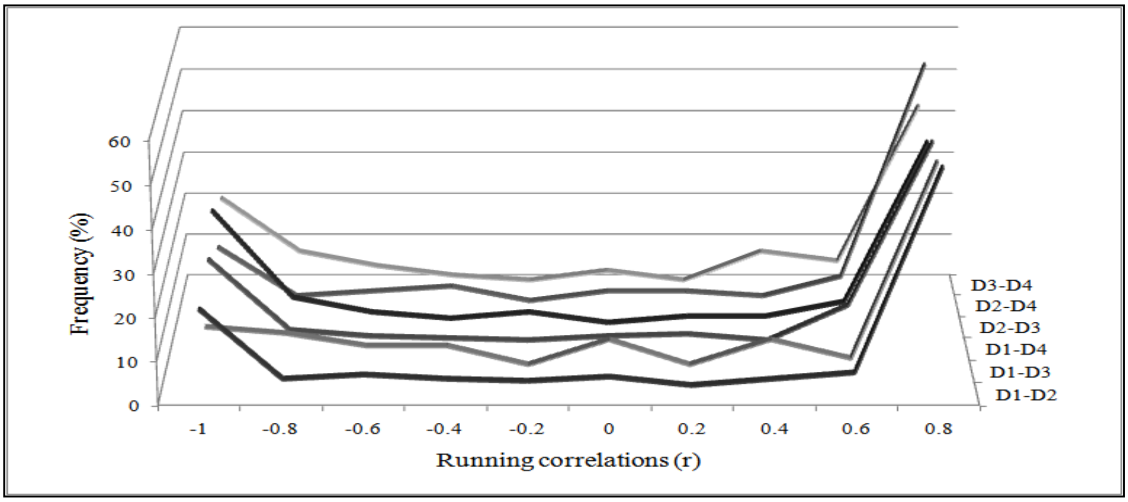

Figure 3. 4 - Landscape of each interpersonal distance pair.

3.5.Discussion

This study examined how information from the performers' inter-relations in the team ball sport of futsal, as a complex social system, regulated the emergence of passing actions. More than simply describing the conditions that afforded a pass in the team ball sport of futsal, we also investigated the coupling tendencies between performers that regulated the emergence of specific interpersonal patterns of coordination. As observed in other complex social systems, our results revealed that decisions to perform specific actions were regulated by coupling tendencies in the distances between individual performers, which sustained the emergence of functional environmental conditions. Analysis of variability measures (%CV) revealed a decrease across trials from the moment at which a teammate performed the pass to the ball carrier (0% of time), to the moment of pass initiation by the ball carrier (100% of time), with the exception of the interpersonal distance between ball carrier and ball receiver. However, the variability in the interpersonal distance between the ball carrier and the ball receiver was not accompanied by changes in interpersonal distances between the ball carrier and the two defenders. The results of running correlations (*r*=1 with 50% of frequency) reinforced the attraction of interpersonal distances between performers to a specific mode of coordination nearest to the moment of pass initiation.

3.5.1. Passing actions are regulated by interpersonal distances between performers

The data showed how interpersonal distances between performers converged to a specific spatial configuration that afforded the opportunity for the ball carrier to pass the ball to a teammate. According to previous research on team sport performance, the opportunities for a ball carrier to perform a pass seem to be guided by simple local behavioral rules on the basis of interpersonal coordination patterns emerging between attackers and defenders (Passos et al., 2011). Our results suggested that the confluence to a specific spatial configuration of different interpersonal distance values between a ball carrier and immediate opponents irreversibly constrained the performers' possibilities for action. That is, the ball carrier is afforded an opportunity to make a pass by identification of a gap between defenders, revealing the incapacity of opponents to intercept the ball. In contrast, the interpersonal distance values between the ball carrier and ball receiver increased in variability to the moment of pass initiation. This finding implies that opportunities to make a successful and penetrative pass, in the attacking half of the pitch, emerges when interpersonal distances values between the ball carrier and the immediate opponents converge to specific values, independent of the distance between the two attackers involved in the passing move. Interpersonal distance was confirmed as the key informational variable that predicted the opportunity for a passing action in the team game of futsal.

As observed in other complex social systems, these findings might indicate that the emergence of specific interpersonal distance values specified properties for passing actions in the team sports context (Fajen et al., 2009; Marsh et al., 2006). As in the study of individual prehension tasks (see as e.g., Cesari & Newell, 1999), the completion of a passing action in team ball sports seems to be regulated by a "pi-number". This is a measure that reflects the performer's capability to regulate their actions in relation to the perception of interpersonal distances with other performers (Marsh et al., 2006). In our results, the "pi-number" can be defined by the configuration of the conditions of the environment in relation to the participant's expertise level in team sports like futsal. Generally, functional interpersonal distance values, critical for successful performance of a pass emerged in spatial configurations when: (i) the distance between the ball carrier and a 1st defender reached a minimum of value of 1.4m; (ii) the distance between the ball carrier and a 2nd defender was a minimum of 3.21m; and (iii) the distance between defenders reached a minimum of 2.8m. These results were specific to this elite sample of team games players and we cannot generalize our data on critical interpersonal distance values to the entire population of Futsal players. As argued by Fajen and colleagues (2009), to perceive the principles that guide the behaviors of sport performers we need to understand the contextual performance constraints with reference to each individual performer's personal characteristics (see also, Araújo & Davids, 2009). The observed values of interpersonal distances between our performers can only be considered as a reference for the emergence of "passing opportunities" for this group of skilled performers. A major challenge for future research on complex social systems in sport is to evaluate whether functional spatial relationships exist to specify passing action affordances for participants of different skill levels and under different team ball sport task constraints.

We also observed that the possibilities for action in our study were not defined when ball carrier received the ball. The dynamics of interpersonal distance values revealed a high level of variability between trials at the beginning of the selected performance sequences. This finding means that performers' behaviors were guided in a prospective way, based on the initial conditions of performance (Bootsma & van Wieringen, 1990). With this level of variability of interpersonal distance values at the beginning of the trials, it is apparent that attackers were constantly adjusting their space for action to achieve a functional position to make a successful pass. To counter this tactic, defenders tried to close the space available for attackers. This dynamic of the competing and cooperation tendencies between performers supported the findings of previous studies demonstrating that participants in sports teams self-organized their behaviors on the basis of structured spatial relations between them (McGarry et al., 2002; Passos et al., 2009).

3.5.2. Interpersonal coupling tendencies specify functional passing actions

At the beginning of each trial different coupling tendencies emerged in all pairs of interpersonal distance values recorded. The high variability observed across trials in r values at the beginning of each trial remained until 70/80% of the time had passed in each trial. At that moment (close to the moment of pass initiation) a convergence in running correlation was observed to values towards 1. This finding implies that, at the moment of the initiation of a pass, a strong positive coupling existed between interpersonal distances values. Thus, the convergence of interpersonal distance values to the moment of pass initiation was regulated by information from the coupling tendencies of the different interpersonal distances. The strength of coupling between interpersonal distance values during performance is what sustained the local interaction rules that governed successful passing performance (Araújo et al., 2006; Passos et al., 2011).

Changes in the interpersonal distance values from the beginning of the trials to 70/80% of time, were also revealed in landscape of running correlations. High positive correlation (i.e., r=1) presented 50% of frequency for all the interpersonal relations and other 50% were distributed by other correlation values. These data reflected the attempts of each individual to change the functional interpersonal relations between him and other participants at the beginning of the trial to create a favorable performance outcome possibility that allows the emergence of the pass (Turvey, 2004). It seems that performers moved to tactically alter interpersonal distance values according to the initial conditions of each performance situation in order to create more favorable team organization patterns (Marsh et al., 2006). It is obvious that performers explored interpersonal behaviors under the boundary conditions of the performance environment providing possibilities for action (Araújo et al., 2006). In a cyclically coupled manner, the behaviors of defenders constrained the attackers' options, and the attackers' explored attacking possibilities afforded by the behaviors of defenders. As observed in other studies, this level of inter-individual variability should be viewed as functional, and part of the constant adaptations of a performer to the actions of other performers, rather than perceived as random movements and system noise in team ball sports (Bootsma & van Wieringen, 1990; Davids et al., 2003).

In this study, performers' actions were sustained by local information generated by the changes in the positions of other performers and vice-versa in accordance with the specific goals of the game. The subtle spatial adaptations observed during performance were based on the action capabilities of each performer, but were also based on judgments about the action capabilities of other performers (Fajen et al., 2009; Richardson, Marsh, & Baron, 2007).Our results emphasize that goal achievement during performance in team ball sports are dependent on the capacity of performers to pick up and use specific sources of environmental information during performance. However, this performance capacity is facilitated by active exploration of the current conditions of the environment that allow the emergence of functional spatial configurations that yield affordances for action (Araújo et al., 2006; Warren, 2006).

In sum, our results support the theoretical notion of emergent patterns of spatial interpersonal organization as a system process that characterizes functional behaviors in team ball sports. The results indicated that interpersonal distances, especially between the ball carrier and defenders, and between both defenders, constituted important sources of information that guided performers' perceptions and actions when attempting to make successful passes. It was observed that skilled performers coupled their actions on court with continuous changes in the emergent spatial relations with other performers. As in other complex social systems, in team sports the actions of individuals are sustained by collective behaviors (i.e., spatial interpersonal relations) through constant changes in informational coupling between individual agents.

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4. Informational Constraints Shape Emergent Functional Behaviors During Performance of Interceptive Actions In Team Sports

4.1.Abstract

This study aimed to capture information-movement couplings that underline decision-making to intercept a ball's trajectory in a competitive performance setting in team sports. Time series data on movement displacements of fifteen male futsal performers (*M* = 23.25, *SD* = 1.96 years) were recorded and digitized with TACTO software during nine competitive futsal games. Ten successful and ten unsuccessful passes were subjected to a detailed spatial-temporal analysis. Time to ball intersection was calculated as the difference between the time of each opponent and the time of the ball to reach the point of interception in each time frame. Our results revealed that at the moment of pass initiation distances between performers constrained success of ball trajectory interception. The mean velocity of defender that intersects the ball was significantly different for successful and unsuccessful passes in the last four proportions of time in trials. Analysis of Time to ball intersection revealed significant differences with large effect sizes at the last three moments of normalized time percentage with positive values to successful passes and negative to zero values to unsuccessful ones. In sum, successful interceptions seemed to be influenced by the continuous regulation of a performer's velocity to changing task conditions. Time to ball intersection was instrumental in shaping the emergent functional behaviors of performers in intercepting the trajectory of a pass in the team sport of futsal.

4.2.Introduction

Decision-making of performers in team games has been considered a complex process that arises from the multiplicity of variables interacting over time to constrain functional behaviors. In sport, a significant body of research has examined how information constrains perceptual-cognitive processes such as decision-making (see e.g., Mann et al., 2007). In that approach, the design of relatively simple performance tasks to study decision-making, based on simple and choice reaction times, response accuracy or eye movement measures has been typically used (Williams & Ericsson, 2005). However, prevalent approaches to the study of perception, cognition and action mask the emergence of unique contextual performance solutions by neglecting the study of how different individuals act in order to generate and detect prospective information to regulate functional behaviors (Davids & Araújo, 2010; Dicks et al., 2010). Indeed, recent work has demonstrated how perceptual-motor behaviors significantly differ in video simulations (e.g., with joystick movement responses) and *in situ* performance conditions (requiring actual interceptive responses) (Dicks et al., 2010; Mann et al., 2007; Pinder et al., 2011a).

Ecological dynamics is an alternative approach that considers the functional behaviors of individuals through establishment of information-movement relations (Araújo et al., 2006). In this approach to studying decision making for action, information is considered to be directly available in the ambient energy arrays of the performance setting (e.g., the optic flow provides specific visual information on environmental properties like movement of objects or individuals) (Gibson, 1979). Perception-action coupling is sustained by the detection and use of specifying variables that support immediate actions and the exploratory behaviors that create opportunities to perceive information to guide actions (Le Runigo, Benguigui, & Bardy, 2005). When detected, such informational variables reveal possibilities for action (i.e., affordances) that emerge from the complementary interactions between a performance environment and the actor

(Gibson, 1979). These ideas suggest that individuals' behaviors during performance are guided by affordance-based control (Fajen, 2007).

The detection of affordances allows individuals to decide how to act in order to achieve an intended goal within converging possibilities for action (Araújo et al., 2006; Fajen, 2007). From this perspective, the process of decision-making comprises transitions in each individual's courses of action that reflect exploitation of affordances, rather than a set of discrete episodes involving choice dilemmas at decision points (Araújo et al., 2006; Brehmer, 1990). However, to perform adaptively, individuals need to refine perception-action couplings by improving their attunement to perceptual variables that inform which actions are possible or not, according to each individual's action capabilities (Fajen, 2005; Jacobs & Michaels, 2007). Ecological dynamics suggests that decision making can be studied by identifying the informational variables that sustain emergent functional behaviors. The identification of functional patterns of behavior over time specifies the adaptation of individuals to constraints of specific performance environments and consequently decision-making processes (Araújo et al., 2006; Warren, 2006). Some previous work has successfully captured cinematically changes in the dynamics of individuals in relation to the performance environment indicating how they acted to achieve a specific performance goal (Araújo et al., 2006; Passos et al., 2008). Hence, decision-making in sport can be understood in physical terms (i.e., based on the spatial-temporal fit between individuals and key features of the performance environment) grounded on the idea that changes in functional actions represent the decision-making behaviors used to achieve a specific performance goal (Araújo et al., 2006), such as intercepting a passed ball in team sports.

In relation to these arguments, different models have shown how visual information from the motion of a projectile can be picked up to regulate and guide an individual's functional interceptive behaviors based on the use of higher order perceptual variables such as 'time-to-contact' (Beek, Dessing, Peper, & Bullock, 2003; Davids, Renshaw, & Glazier, 2005). The pioneering work of Lee (1976) contributed to understanding of prospective guidance of movements, for example, on the basis of the rate of closure of the gap between an individual and an approaching object. The time-to-contact of a particular gap is defined by the time that a specific distance between an object and individual would take to close if the rate of closing were constant (Lee, 1976). Other models have also considered the required velocity of an individual to intercept a moving projectile (Beek et al., 2003; Davids, Renshaw et al., 2005). This information-based approach takes into account the ratio between the current distance of an intercepting limb to the end position of ball trajectory, in one movement axis, and the first-order time-to-contact between the current ball position and the trajectory end position (Bootsma, Fayt, Zaal, & Laurent, 1997; Montagne, Fraisse, Ripoll, & Laurent, 2000; Peper, Bootsma, Mestre, & Bakker, 1994). Currently, there is no evidence suggesting that one model may explain the regulation of interceptive actions better than the other (Beek et al., 2003).

In dynamic environments like team ball sports, informational constraints change over time due to the variability of the interactions between performers and the environment (Fajen et al., 2009). Thus, studying interceptive movements are crucial because they highlight the spatiotemporal capacity of performers to operate effectively in dynamic performance environments (e.g., to successfully pass or intercept a ball) (Davids, Renshaw et al., 2005). For example, in team ball sports like futsal (five a side indoor soccer) the trajectory of a pass may be intercepted by an opponent at one moment and not a few seconds later. There may be many reasons for these performance variations (see J. Smith & Pepping, 2010), but to successfully intercept a passed ball the performer needs to move at a specific velocity to arrive at the interception point at the same time as the ball (Savelsbergh & Bootsma, 1994). More precisely, to intercept the trajectory of a passing ball, an opponent should be positioned in between a ball carrier and a ball receiver, maintaining a minimum distance to the ball's trajectory and requiring a minimum speed to intercept the pass (Fajen et al., 2009). Position and motion of performers, the ball's direction of motion at the moment of pass initiation, angular approach of ball, and position and motion of other performers are potential perceptual variables that might constrain the affordances to intercept a passing ball trajectory in team sports (Fajen et al., 2009; Montagne et al., 2000).

In one study of time-to-contact information in the team sport of rugby union, significant correlations were found between pass distance and pass duration (i.e., the type of pass) and the time to contact between the performer who made the pass and his immediate opponent (Correia, Araújo, Craig, & Passos, In Press). These findings suggested that the decision for passing actions might be based on information from time-to-contact to a defender. However, there is a need for more research to understand how the relative positioning of performers and the ball might constrain decision-making behaviors of individuals in attempts to intercept the ball (Fajen, 2007).

In this study we aimed to extend previous research on interceptive actions in team games by investigating differences in the nature of spatial-temporal variables observed in performance of successful and unsuccessful passes. We expected that, by examining time to ball interception (TBI) (calculating a performer's distance to the ball's displacement trajectory, the velocity of the ball and of a performer attempting an interception) it would be possible to specify the process of decision making that allows the achievement of successful and unsuccessful passes, differentiated by positive and negative values of TBI, respectively.

4.3.Method

4.3.1. Participants

Fifteen Portuguese male senior (*M* =23.25, *SD* =1.96 years) players from the National Futsal University squad participated in this study. All participants gave prior informed consent and the experimental protocol was approved by the local university institution's ethics guidelines.

4.3.2. Task and procedures

Futsal is a five a side indoor soccer game that is played on a court of 40m length x 20m width. During performance the main goal of each team is to win a game by scoring more goals than the opposition. In this experiment, performers were grouped into three teams in order to create competitive performance contexts. The task comprised nine competitive futsal games each of five minutes duration, in which performers attempted to achieve the main performance goal of the game. Each team competed against the other teams on three separate occasions.

Performance was recorded by a digital camera (frequency=25Hz) placed in a superior plane at an angle of 45° to the mid-court line, to capture the movement displacement trajectories of all performers and the ball. The video recording was digitized with TACTO software (see Duarte et al., 2010, for additional information). The obtained coordinates were transformed into real coordinates using the direct linear transformation method (2D-DLT) and filtered with a Butterworth low pass filter (6Hz) (Winter, 2005).

4.3.3. Data analysis

For the purpose of the present study, passes performed into the defensive team's 'surface' area (i.e., the area bounded by the defending players' positioning on the court) were analyzed in detail. Passes in which the ball was intercepted by a targeted teammate were considered as successful and those intercepted by an opponent as unsuccessful. Performance during ten successful and ten unsuccessful passes was subjected to a detailed spatial-temporal analysis. From all the performers involved in each trial (i.e., 10), only the behaviors of four key individuals were considered: (i) the performer with the ball (ball carrier), (ii) the targeted teammate who received the ball, (iii) the nearest opponent to the ball carrier (D1), and (iv), the second nearest opponent to the ball carrier (D2) (see Figure 4.1.).

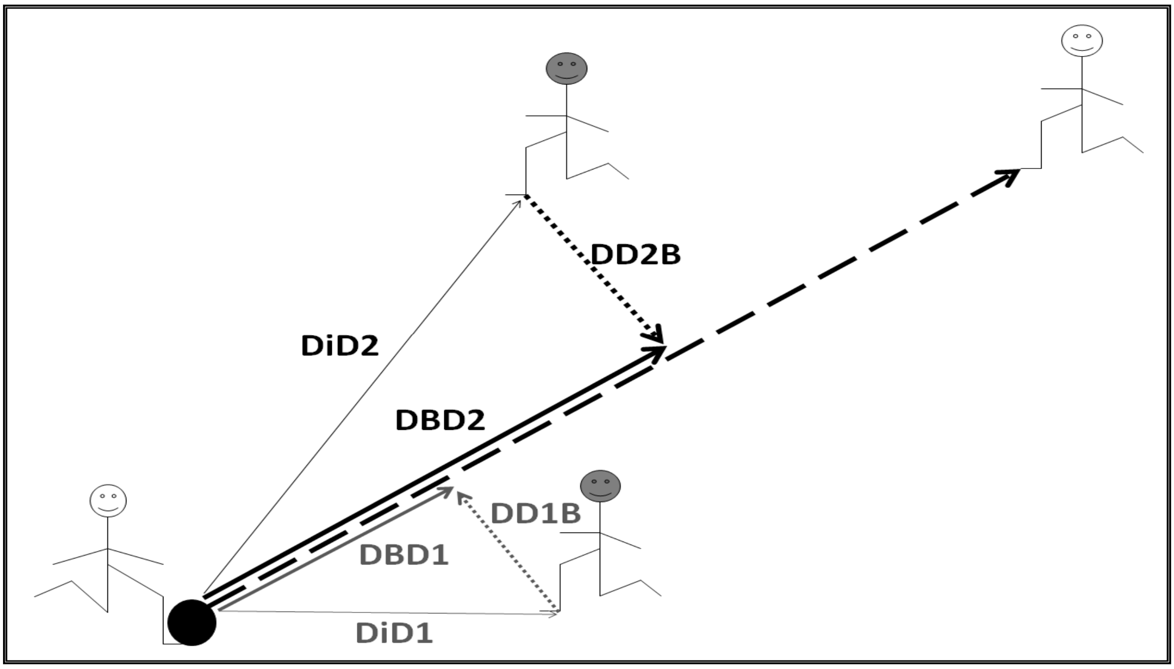

Figure 4. 1. - Representation of a pass on the moment of pass initiation. The white performers represent the attackers, the grey performers represent the defenders, and the ball is represented by the black circle. DiD1 represent the Euclidean distance between the ball and D1 and DiD2 represent the Euclidean distance between the ball and D2.The black dashed line represent ball trajectory and DD1B and DD2B represent the lateral Euclidean distance between the nearest point of the position of each defender to the ball's trajectory projection at a given instant.

To characterize the environmental conditions for successful and unsuccessful passes, we calculated the following variables: (i) each opponent's Euclidean distance to the ball; (ii) each opponent's angle to the ball (measured by marking the location of each performer and the ball in the current frame and the location of the ball in subsequent frames); and (iii) maximum velocity of the ball between the moment of pass initiation and the moment of ball interception (either by an opponent performer or a targeted teammate).

To measure the time-to-contact between each performer and the ball we considered the time remaining for ball interception in each frame between the instances of pass initiation and ball interception (Peper et al., 1994). Based on each performer's Euclidean distance and angle to the ball, we used Pythagoras' theorem to calculate the following variables (see Figure 4.1.): (i) distance between the nearest point of the position of each opponent to the ball's trajectory projection (D_{D1B} and D_{D2B}); (ii) distance between the ball's position to the point of the nearest position of each opponent to the ball's trajectory projection (D_{BD1} and D_{BD2}); (iii) velocity of each opponent. The velocity of each performer was calculated at each frame by the rate of change of the distance between his current position and the nearest point of the ball's projection trajectory ($\dot{D}_{D1B}$ and $\dot{D}_{D2B}$); (iv) velocity of the ball ($\dot{D}_{BD1}$ and $\dot{D}_{BD2}$).

Equations 1 and 2 represent time to ball contact (TB) and time to the opponent's interception (TD). In equation 1, TB is expressed as the ratio between the distance of the ball's current position to the ball's projection plane onto the axis of each performer (D_{BD1} and D_{BD2}), and the rate of change of this variable in each time frame ($\dot{D}_{BD1}$ and $\dot{D}_{BD2}$). In equation 2, TD is expressed as the ratio between each performer's current distance to the nearest point of the ball's projection trajectory (D_{D1B} and D_{D2B}) and the performer's velocity ($\dot{D}_{D1B}$ and $\dot{D}_{D2B}$).

$$TB = \frac{D_{BD}}{\dot{D}_{BD}} \quad (1) \qquad TD = \frac{D_{DB}}{\dot{D}_{DB}} \quad (2)$$

Based on the work of Watson et al. (In press) we calculated the difference between the time of each opponent and the time of the ball to reach the point of interception ($TBI1=TD1-TB1$ and $TBI2=TD2-TB2$) in each time frame. If an opponent's current time to intercept the ball was equal or smaller than the current time for the ball to reach the same point, TBI assumed zero or negative values. If TBI assumed positive values, the opponent's time to reach the ball was greater in magnitude than the time the ball would take to reach the same point.

For statistical comparison purposes, each trial was normalized to the total time taken to perform the trial. The value of 0% corresponds to the moment of pass initiation. The value of 100% was the moment of pass interception by an opponent (for unsuccessful passes) or the moment at which the ball passed at a minimum distance to the axis of the opponent's displacement trajectory, without interception (for successful passes). The data were averaged for every 10% of the total normalized time in each trial. The comparison between the velocity values of performers and the TBI of successful and unsuccessful passes was analyzed using paired two-tailed Student's t-test. A one way analysis of variance (ANOVA) was used to examine differences in distances and angles between performers and the ball for successful and unsuccessful passes at the moment of pass initiation.

4.3.4. Reliability

One of the 20 trials subjected to data analysis was randomly selected and the data trajectories of the ball and performers were re-digitized by the same experimenter. Data were then assessed for accuracy and reliability using technical error of measurement (TEM) and coefficient of reliability (*R*), respectively (Goto & Mascie-Taylor, 2007). TEM and %TEM are measures of accuracy that consider the standard deviation between repeated measures which permits the calculation of a coefficient of reliability. The TEM yielded values of 0.159 meters (.24%), and 0.235 meters (.36%) for performers, and the ball, respectively. The coefficient of reliability showed good reliability of the data recorded for the performers (R=.982) and ball (R=.966).

4.4.Results

4.4.1. Initial conditions for pass performance

Analysis of performance at the moment of pass initiation revealed significant differences with medium effect sizes between successful and unsuccessful passes for the distance between the ball location and each opponent r, respectively, for D1, $F(1,18)=12.74$, $MSE = 6.23$, $p < .001$, $\omega = .60$, and D2, $F(1,18)=15.71$, $MSE = 15.70$, $p <. 05$, $\omega = .49$ (see left panel Figure

4.2.). In contrast, the values of angles defined between ball location and each opponent were not significantly different between successful and unsuccessful passes, respectively, for D1, *F*(1,18) = 3.7, *MSE* = 4509.28, *p* > .05, ω = .31 or D2, *F*(1,18) =. 36, *MSE* = 776.90, *p* > .05, ω = .12 (see right panel Figure 4.2.). These results indicated that the initial conditions of pass performance were constrained by the values for distances between opponents and the ball, with larger distance values being associated with unsuccessful passes.

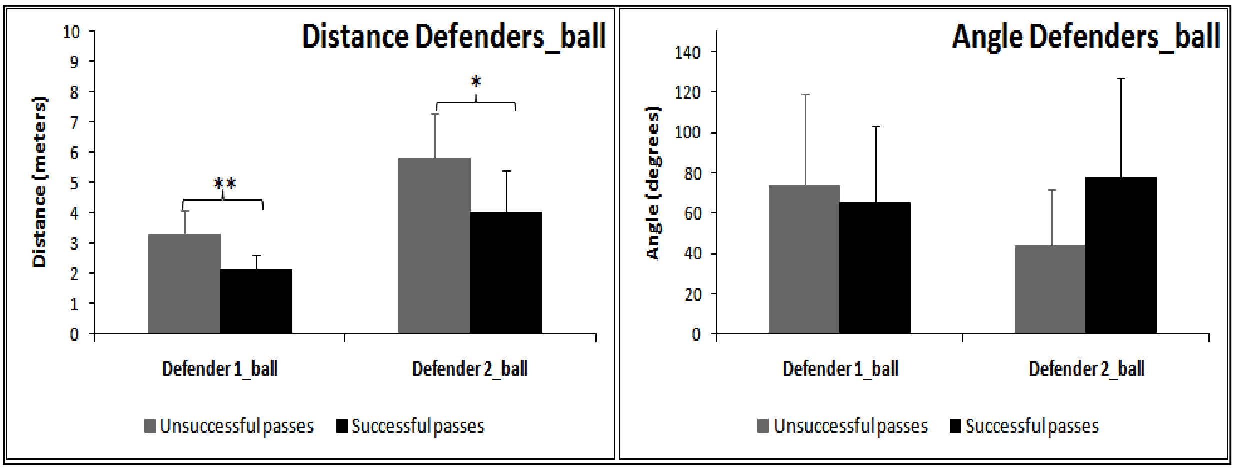

Figure 4. 2. - Kinematic variables for successful and unsuccessful passes at the moment of pass initiation. A) Left panel represent the mean distance between performers and ball; B) Right panel represent the mean angle between performers and ball;

4.4.2. Velocity levels of the ball and each performer

The maximum ball velocity observed after the moment of pass initiation was not significantly different between successful and unsuccessful passes, *F*(1,18) = .189, *MSE* = 3.96, *p* > .05, ω = .08. There were no significant differences (*p* > .05) between successful and unsuccessful passes in the mean velocity of D1, during the whole performance timeline. Data on the velocity of D1 over time, in exemplar successful and unsuccessful trials, revealed a continuous decrease in these values until 60% of the timeline, with an increase at the end of the trial for both successful and unsuccessful passes (see left panels, Figure 4.3.).

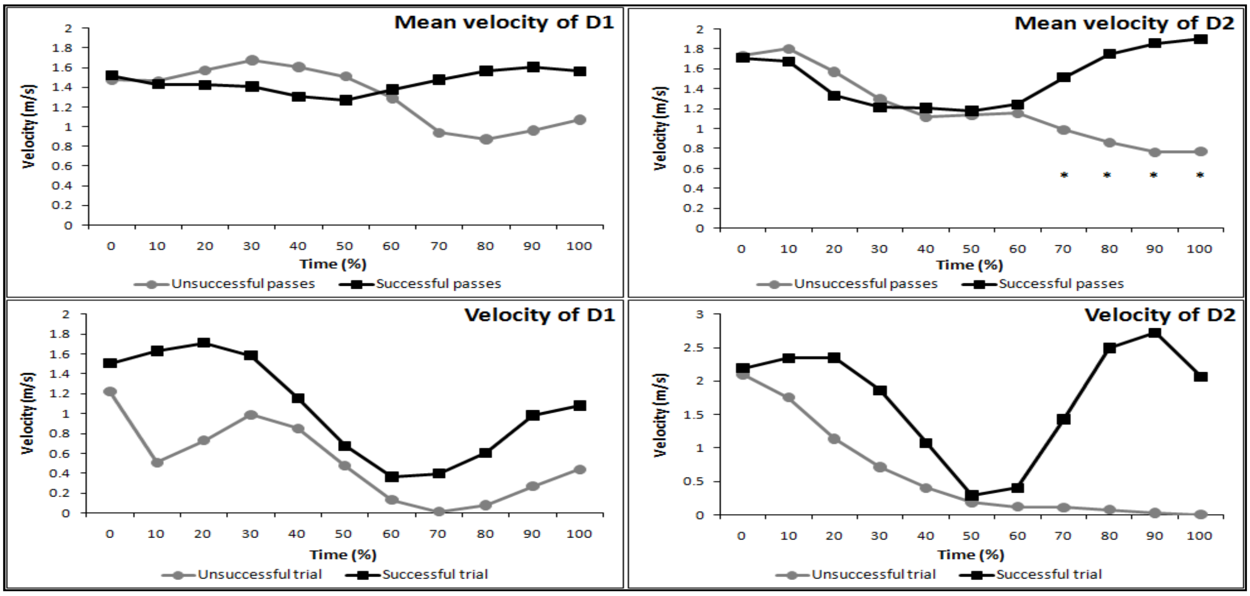

Figure 4. 3. - Performers' velocity for successful and unsuccessful passes: A) Upper panels represent the mean velocity of D1 (left panel) and D2 (right panel). B) Lower panels represent an exemplar trial of velocity of D1 and D2.

Conversely, the mean velocity of D2 over time was significantly different for successful and unsuccessful passes, with large effect sizes in the last four proportions of time in trials (70%: t(9) = -2.26, $p < .05$, $r = .83$; 80%: t(9) = -3.579, $p = .006$, $r = 1.54$; 90%: t(9) = -4.159, $p = .004$, $r = 1.89$, and 100%: t(9) = -5.163, $p = .001$, $r = 2.64$). Data on the velocity values of D2 over time in exemplar successful and unsuccessful trials revealed a continuous decrease in velocity until 60% of the timeline. After that, the velocity of D2 in unsuccessful trials stabilized around zero, and in successful trials it increased to the end of the trial (see right panels, Figure 4.3.). These results expressed the behavioral difference of D2 during successful and unsuccessful passes, especially towards the end of the trial.

4.4.3. Time to ball interception (TBI)

Analysis of TBI 1 over time did not reveal significant differences between successful and unsuccessful passes ($p > .05$). It is important to note that at 100% of trial time, TBI 1 presented positive values for all trials, regardless of passing success, t(9) = .813, *p* > .05, *r* = .28 (see left panels, Figure 4.4.). This finding indicates that D1 never intercepted the ball.

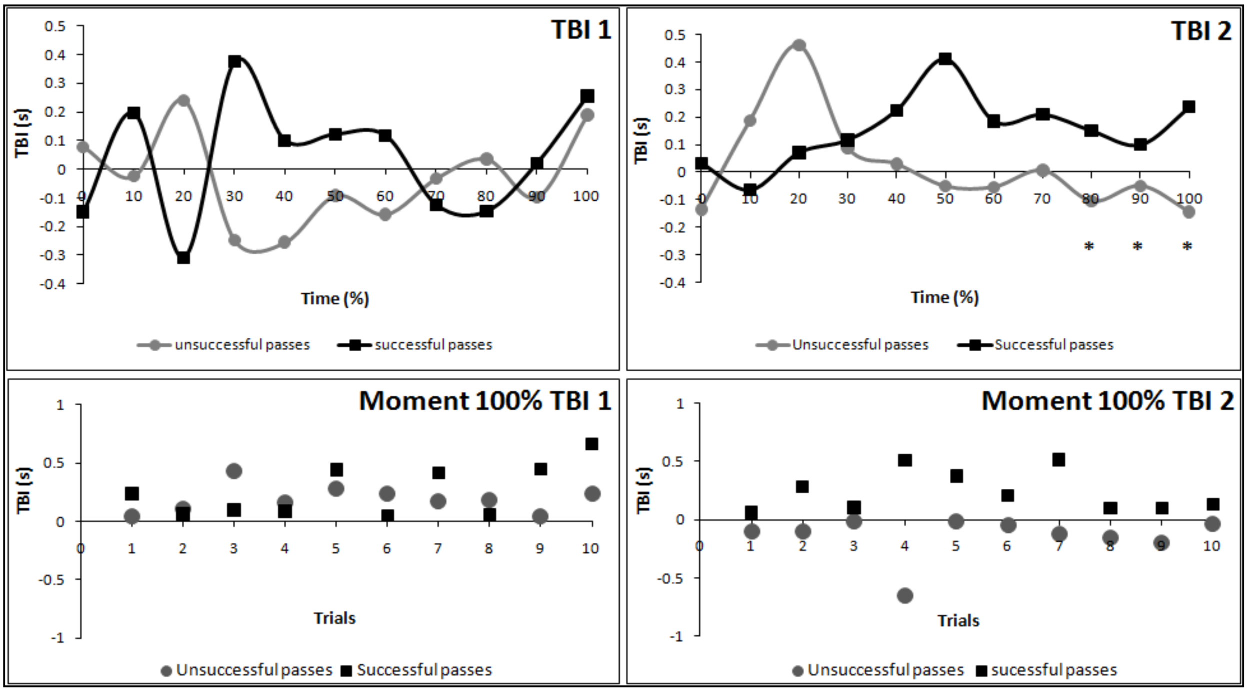

Figure 4. 4. - Representation of TBI. A) Upper panels represent the successful and unsuccessful passes measured over time. Left panel represent the TBI for D1 and Right panel represent TBI for D2. B) Lower panels represent the obtained value of TBI in each successful and unsuccessful trial at the 100% of time moment.

On the other hand, analysis of TBI 2 revealed significant differences with large effect sizes at the last three moments of normalized time percentage (80%: t(9) = -2.27, *p* = .05, *r* = .87; 90%: t(9) = -3.153, *p* < .05, *r* = 1.30, and 100%: t(9) = -3.129, *p* < .05, *r* = 1.29) (see right panels, Figure 4.4.). As expected, at the end of the trial, successful passes were associated with positive values of TBI 2, whilst unsuccessful passes were related to negative values around zero.

4.5.Discussion

In the present study we aimed to examine how spatial-temporal information that is directly available within the performance environment guides decision-making processes of performers during team games. To achieve this aim we studied the functional behaviors of individuals attempting to intercept the trajectory of a passing ball in futsal, as a task vehicle. Our results revealed that initial performance conditions constrained successful interceptions. When opponents were located further away from the ball, they were more likely to intercept the trajectory of a pass (leading to a higher probability of unsuccessful passes). Moreover, the velocity of a performer who was able to intercept the trajectory of a pass was significantly different than when the same individual failed to intercept the ball, at the end of a trial. In agreement with our hypothesis, the variable 'time to ball interception' captured how the dynamic relations between information and movement might constrain possibilities to intercept the trajectory of a pass.

4.5.1. Initial spatial-temporal conditions of pass performance constrained possibilities for action

Analysis of the initial conditions of performance suggested that the distance between interacting performers and the ball at the moment of pass initiation is an informative variable that constrains an individual's ability to intercept the ball's trajectory. When opponents successfully intercepted the trajectory of a pass, the initial distance between the ball and each individual was significantly larger than when the pass was successfully received by the target performer. The angle between performers and the ball was not significantly different for successful and unsuccessful passes. By increasing the distance to the ball, each performer ensured that additional time was available to move towards the interception point and intercept the pass by decreasing the required speed (Fajen et al., 2009). This observation suggests that the decision to intercept the pass was not only dependent on individual cognitive processes but also on the spatial-temporal relations between key features of the environment which emerged under specific performance constraints. However, this finding does not imply that, under the same initial performance conditions (i.e., large distances to the ball), all performers will be able to intercept a pass. The value of this strategy depends on each individual's action capabilities and his/her exploitation of existing affordances for action (Araújo et al., 2006; Davids et al., 2001). Depending on the variations between their action capabilities, individual performers may be able to use different action patterns to achieve the task goal of interception (see Dicks et al., 2010 in the study of penalty kicks in football). In order to adapt their goal-directed behaviors to the requirements of the environment, individual performers must also be attuned to the relevant information sources to calibrate their actions (Araújo et al., 2006; Fajen et al., 2009; Jacobs & Michaels, 2007). These findings highlight the importance of sport psychologists adopting an individualized approach to understanding decision making for action during performance in team games.

The results of this study are in line with the data of Correia et al. (In Press) which revealed that, prior to the moment of pass initiation, current information perceived during the unfolding interaction (the closure of a gap with an immediate opponent) constrained the decision making processes for a pass performed. These results are also in agreement with previous studies on manual interceptive actions in which the success of interception was influenced by specific values of initial lateral distance and the initial time remaining until the ball crosses the hand's axis of displacement (Montagne et al., 2000; Peper et al., 1994).

4.5.2. Performers' adaptations to the environment are based on changes in velocity

To intercept a ball in team games, performers need to constantly adapt their movement velocity in accordance with the current spatial-temporal constraints. The variations in movement velocity reflect the decision-making process of performers to achieve the goal, intercepting a ball in motion. To exemplify, analysis of displacement velocity data for D2 revealed significant differences between successful and unsuccessful passes towards the end of the trial (see Figure 4.3.). During unsuccessful passes, for D2 displacement velocity generally decreased towards the end of the trial. For successful passes the displacement velocity of D2 tended to decrease up to

60% of the performance timeline and then increased again until the end of the trial. These findings suggested that latencies in the decision making processes of a defender to increase movement velocity in the direction of ball trajectory prevented him from intercepting the ball. When performers decided to increased their displacement velocity at 60% of the performance timeline, the available time to reach the interception point was not sufficient given their individual action capabilities. This outcome implies that the decision making of individuals in team games is founded on changes in their own movement velocity at specific moments in time relative to the kinematic properties of a moving projectile to intercept (particularly the direction and speed of displacement) (Bootsma et al., 1997; Chardenon, Montagne, Buekers, & Laurent, 2002).

4.5.3. Time to ball interception guides performers' behaviors

Our results revealed a general decrease in the mean TBI for D2 in unsuccessful trials, which stabilized at negative values from 70% of time onwards in a trial. Conversely, in successful passes, the mean TBI revealed positive values from 20% of time onwards. However, significant differences were observed only for the three last blocks of percentage of time (80% to 100%) in which a convergence in values of TBI was observed. At the moment of ball interception (i.e., at 100% of trial time) it was observed that time to ball interception presented positive values for all unsuccessful passes and negative values for successful ones. In agreement with our hypothesis, by measuring TBI during performance it was possible to identify achievement of successful or unsuccessful passes.

The absence of significant differences in TBI until 70% of trial time was a consequence of the specificities of each situation and revealed performers' attempts to change the spatial-temporal relations with opponents and especially with the ball. These results are in line with the findings of Passos and colleagues (2008) in one-on-one sub-phases of rugby union. They observed that, at the beginning of the trials random fluctuations in relative velocity of performers existed that may have expressed the exploratory decisions and actions of individuals in their study. The observed inter-trial variability in their study can be considered as more than mere system noise since it reflected movement adaptations to generate prospective information to guide performance (Araújo et al., 2006; Dicks et al., 2010; Passos et al., 2008). Our results also suggested that interception of the ball was dependent on the adaptations of performers to the time that the ball took to reach the interception point, observed in the dynamics of movement velocity for successful passes. This explanation suggests that the lack of success of D2 in intercepting a pass could have been due to insufficient spatial-temporal adaptations to environmental constraints in a specific time period (Chardenon et al., 2002; Fajen et al., 2009). Moreover, the lack of significant differences at the beginning of the trials revealed that the result of each trial was not defined from the beginning, but was dependent on the constant decision making processes of individuals during performance. In this adaptive process it is important to pick up the permanent variations in the distance of performers to the ball's trajectory and their current velocity in relation to the ball (Fajen et al., 2009; Montagne et al., 2000).

In sum, this study suggested that the variable TBI was instrumental in shaping the emergent functional behaviors of performers in intercepting the trajectory of a pass in the team sport of futsal. This variable was revealed as a reliable measure of the information-movement coupling that specifies the achievement of successful or unsuccessful interceptive actions. The cinematic capture of changes in the dynamics of individual performers relative to the performance environment (e.g., changes in performers' movement velocity in the direction of the pass trajectory) allowed us to gain some insights into decision-making processes during team game performance. Future research is needed to test the effects of information manipulation on the movement adaptations of participants by highlighting some information and suppressing other sources during similar tasks. Understanding whether different outcomes can be influenced by different visual search strategies for information and performance using eye-tracking systems or virtual reality systems is also a challenge for future research.

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5. Interpersonal Coordination and Ball Dynamics in Futsal

5.1.Abstract

In this study, we reported an investigation of the patterned movement behaviors of players for a specific sub-phase of the game of futsal, namely when the goalkeeper for the attacking team is substituted with an extra outfield player. The movement trajectories of the ball and players were recorded in both lateral and longitudinal directions and investigated using relative phase analysis. Some differences in phase relations between different playing dyads were noted, indicating specificity of phase attractions, or otherwise, for certain players. In general terms, the defenders demonstrated strong in-phase attractions with the ball and with each other whereas weaker phase attractions, indicated by increased relative phase variability, was observed for the attackers and ball, as well as between attackers themselves. These results demonstrate different coordination dynamics for the defending and attacking dyads, from which we interpret evidence for different playing sub-systems consistent with different team objectives linked together in an overarching game structure. In keeping with dynamical systems theory, we viewed this sub-phase of futsal as being characterized by coordinated behavior patterns that emerge as a result of self-organizing processes. These dynamic patterns are generated within functional constraints, with players and teams exerting mutual influence on each other.

5.2.Introduction

The scientific analysis of team sports has tended to focus in the main on identifying discrete performance variables, and reporting on their instances using descriptive measures such as data frequencies, and action sequence chains. The main aim of these methods has been to document sports behavior in descriptive fashion, generally by identifying *who* performs the action, *what* kind of action is produced, *where* on the field of play the action is observed, and *when* the action is taken (see McGarry, 2009). As noted, this descriptive process for analyzing sports performance loses some of the important context in which the observed sports behaviors were produced (McGarry, 2009), the consequence being that meaningful interpretation of the information gathered by game analysis is strongly dependent on game context (Travassos et al., 2010).

To advance scientific understanding, it should be recognized that new coordination patterns of sports behavior emerge as a result of constantly changing conditions for players and/or teams (Araújo & Davids, 2009). Thus, behavior on the game and on its sub-phases should be viewed as an adapting self-organizing process whose patterned features emerge from the playing interactions operating under various constraints (Davids et al., 2008). The collective behaviors produced by team sports should not then be considered the aggregate result of individual playing behaviors (Araújo et al., 2006) but, instead, a synergistic result of cooperation and competition among players of the same team and between players on opposing teams, respectively (Gréhaigne et al., 1997; Lames, 2006; McGarry et al., 2002). Thus, the dynamical behavioral structure of team sports may be investigated at different levels, from individual player interactions (e.g., Bourbousson et al., 2010a) to collective team interactions (e.g., Bourbousson et al., 2010b), with the varying information exchanges among playing dyads, and their many possible combinations afforded by team sports, comprising the underlying basis for collective game behavior (McGarry et al., 2002).

Investigating sports behaviors as self-organizing dynamical systems requires a collective variable that describes the behavioral dynamics (McGarry et al., 2002; R. C. Schmidt et al., 1999). Stability in a given collective variable indicates attraction to certain patterns of coordination whereas instability, or variability, suggests a meta-stable dynamical system that is prone to system changes, a result of the competing dependencies and independencies among system parts (Kelso, 2009). For general review of dynamical systems theory for human action and perception, see Kelso (1995).

Various studies have reported on the coordination dynamics of different sports in an attempt to demonstrate formal properties of self-organizing systems when expressed using different variables. Investigations of sailing behavior (Araújo et al., 2006), basketball (Araújo et al., 2006), boxing (Hristovski et al., 2006), and rugby (Passos et al., 2009) used measures of displacement such as distances, velocities, and angles as collective variables. Other investigations of squash (McGarry, 2006; McGarry, Khan, & Franks, 1999), tennis (Lames, 2006; Palut & Zanone, 2005) and basketball (Bourbousson et al., 2010a) used relative phase to investigate coordination properties. The relative phase is a high dimensional informational variable that permits the quantitative expression of the spatial-temporal relations between two oscillating agents (Oullier & Kelso, 2009) (e.g., sports players). Common phase relations observed are in-phase (0º) and anti-phase (180º), where both agents are at the same or opposite places in their particular cycles, respectively. Put another way, the in-phase and anti-phase relations correspond respectively to symmetrical and anti-symmetrical periodic relations between agents (Kelso & Engstrøm, 2006).

Bourbousson et al. (2010a) reported in-phase attractions between basketball players in the longitudinal (basket-to-basket) direction and both in-phase and anti-phase coordination patterns in the lateral (side-to-side) direction. The anti-phase coordination pattern was observed for the wing attack players, a result attributed to both players increasing team width when attacking and reducing team width when defending. These findings imply that informational constraints such as the relative locations of the players with respect to the basketball hoops, and their positional duties given the game objectives, may be important in shaping the behavioral coordination dynamics.

The ball dynamics constitute an additional important informational constraint on game behavior in team sports (Davids et al., 2008; McGarry, 2009). In a wider context, a reciprocal relation between the ball and players may be considered thus, the ball constrains the spatial-temporal behaviors of the players on many levels, from the individual (player) through to the collective (team), and the dynamic playing configurations of the players and teams likewise constrain the ball dynamics. Investigating the ball kinematics in sports games is therefore expected to offer useful additional information for understanding the coordinated behaviors produced by team sports. This investigation advances existing research on team sports as self-organizing complex systems by analyzing the space-time movement trajectories of the ball kinematics, as well as those of the players.

Futsal is a FIFA regulated five-versus-five indoor football game played on a 40 x 20 meters hard surface court, or pitch. As with other team sports, futsal players cooperate with team members in pursuit of common aims, the principal ones being to score goals for the team when in possession of the ball, and to prevent goals being scored against the team when the opposing players have the ball. Towards the end of futsal competition, a common game strategy is for the trailing team when in possession of the ball to substitute the goalkeeper for an extra outfield player, a game phase that we will refer to as five-versus-four plus goalkeeper (5-v-4+GK). This game strategy affords the trailing team numerical outfield player advantage with the express purpose of increasing goal scoring opportunities. The 5-v-4+GK game is usually played in the half of the pitch whose goal the losing team is attacking, not least because of the game rules ("The player that substitutes the goalkeeper in the offensive team may not play the ball a second time until it has been touched by an opponent or has crossed the halfway line.” (FIFA, 2008). Subsequent to data collection, a 2010 FIFA rule change was introduced stipulating that the substitute goalkeeper after playing the ball may play the ball only when (i) he/she is playing in the attacking half of the pitch, or (ii) the opponents have made contact with the ball.).

Strategic goalkeeper substitution for the trailing team is an important part of a futsal match as the following example attests. In the final four of the UEFA Futsal Cup in Lisbon, 2010, half of the goals scored in the last five minutes occurred using a 5-v-4+GK strategy. Importance of the 5-v-4+GK strategy is further indicated in its common usage by coaches in game practice. For these reasons, together with the possibility of changing playing dynamics by virtue of the additional attacking outfield player, we investigated the 5-v-4+GK futsal sub-phase for coordinated self-organizing dynamical behavior. The expectation is that the defending players will exhibit largely invariant phase relations as they defend their goal using a zonal defensive strategy, whereas more varied phasing relations for the attacking players are anticipated as these players look to probe the defensive structure for possible goal scoring opportunities. These predictions are consistent with the general premise of defenders trying to maintain symmetry with the attackers, and attackers looking to break symmetry with the defenders, suggested previously (McGarry et al., 2002).

5.3.Method

5.3.1. Ethics

This study was approved by the research ethics committee of the Faculty of Human Kinetics, Technical University of Lisbon, and followed the guidelines specified by the American Psychological Association.

5.3.2. Participants

Fifteen male senior players of the National Futsal University Team in Portugal were invited to participate in this study (*M* = 23.25 years, *SD* = 1.96 years), with each player giving informed consent before data collection. Participants were grouped into three teams of five players each.

5.3.3. Data collection

Each team competed against the other teams on three separate occasions yielding nine 5-v-4+GK game practice sessions. The five minute practice sessions were confined to the attacking half of the pitch and approximate typical game conditions for 5-v-4+GK futsal sub-phases. Teams competed in two consecutive sessions so producing work schedules consistent with the general physiological demands of futsal competition (Castagna, D'Ottavio, Granda-Vera, & Barbero-Alvarez, 2009). The Official Futsal Rules (FIFA) was observed throughout game practice.

The movements of ball and players were video recorded at 25 Hz using a digital camera placed in the superior plane and positioned 45° to the middle field line. For purposes of data analysis, all players were assigned a unique identifier by virtue of their membership to the attacking (A) or defending (D) team, as well as their starting position at the onset of the practice session (see figure 5.1.).

5.3.4. Data analysis

From the available data, the movement trajectories of the ball and players from 21 trial sequences ending with a shot at goal were digitized by the first author using TACTO software (Fernandes, Folgado, Duarte, & Malta, 2010). The trajectories of the ball and players were followed in separate instances in slow video motion using a computer mouse, with the image coordinate location of any player at any instant being recorded by projecting the gravity centre, as perceived, to the playing surface. The digitized coordinates were then transformed to pitch coordinates using a direct linear transformation method (2D-DLT) before being subjected to a 6 Hz low pass filter (Winter, 2005). In this way, two time series were obtained for the ball as well as the individual player coordinates, that data being the lateral (i.e. side-to-side) and longitudinal (i.e. forward-backward) displacements on the pitch. By convention, the bottom left corner of the half-pitch was assigned zero coordinates (see Figure 5.1.).

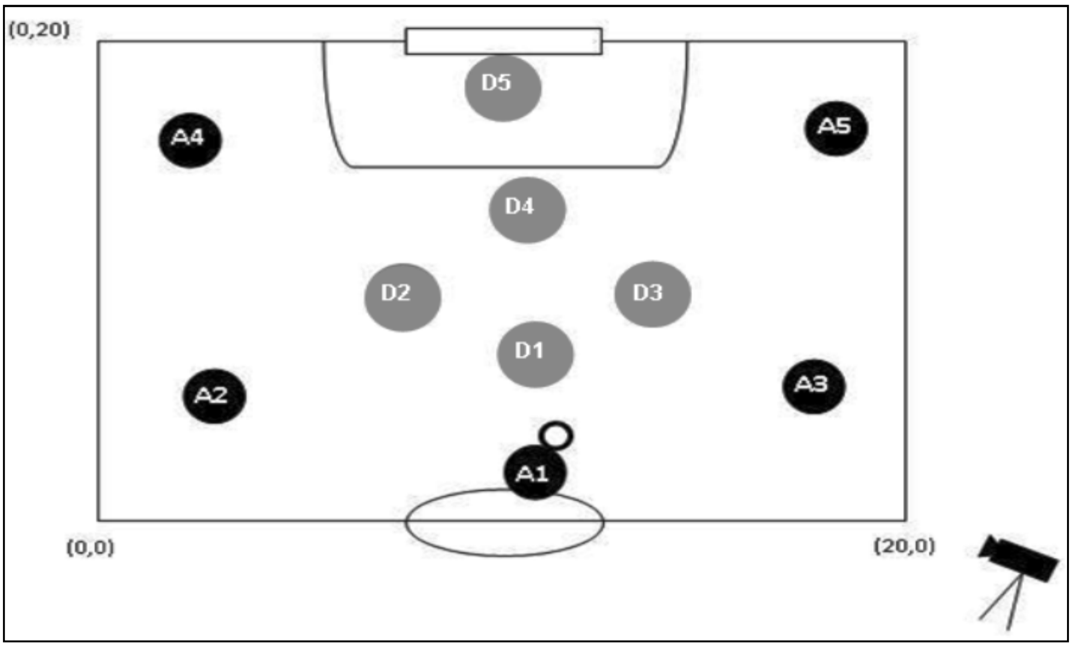

Figure 5.1. Schematic view of the pitch (attacking half only), the camera location, and the player identities based on team membership and starting positions (A – Attackers and D – Defenders).

The relative phasing of the time series data were obtained using Hilbert transform (Palut & Zanone, 2005) computed in MATLAB R2008a software (The MathWorks Inc, Natick, MA, USA). The relative phase histogram data were then subjected to 12x2 mixed model ANOVAs, with repeated measures on the relative phase bins and the second factor being direction (lateral-longitudinal) or team (attack-defense), as appropriate. The ANOVAs were subjected to Mauchly's sphericity test and, when necessary, the Greenhouse-Geisser correction procedure was used to adjust the degrees of freedom. Significant ANOVA results were followed up with

Bonferroni post hoc analyses. Statistical analysis was conducted using SPSS 18.0 software (SPSS Inc., Chicago, USA).

5.3.5. Reliability

One of the 21 trials subjected to data analysis was selected at random and the data trajectories of the ball and players re-digitized by the same author. The data were then assessed for accuracy and reliability using technical error of measurement (TEM) and coefficient of reliability (*R*), respectively (Goto & Mascie-Taylor, 2007). The TEM and %TEM are measures of error (or accuracy) that assess variability between repeated measurements. (Note. TEM = $\sum D^2/2N$, where D is the difference between pre and post measures and N is the sample size, and %TEM = 100*TEM/X, where X is the grand mean of the pre and post measures). The coefficient of reliability was obtained from $R = 1–TEM^2/SD^2$, where SD is the standard deviation of all measures. The TEM yielded values of 0.248 meters (3.645%), 0.185 meters (1.749%) and 0.235 meters (2.361%) for attackers, defenders and the ball, respectively. The coefficient of reliability showed good reliability of the data for the attackers (R = .968), defenders (R = .964) and ball (R = .993).

5.4.Results

5.4.1. Ball dynamics

As expected, the ball dynamics in each trial sequence exhibited typical patterns of game behavior associated with futsal competition, with a greater lateral distribution of the ball (M = 12.58 m, SD = 5.09 m) than longitudinal distribution (*M* = 8.14 m, *SD* = 4.15 m). These distributions stem from the separate oscillatory ball dynamics observed in both lateral and longitudinal directions.

5.4.2. Coordination dynamics between the defenders and ball

Figure 5.2. (upper panels) present the relative phasing frequency histograms in both lateral and longitudinal directions obtained from all observations of defenders and ball. Analysis of variance revealed a main effect for relative phase, $F(1.31,26.20) = 63.82$, $p < .001$, but not for direction, and a significant interaction between both factors, $F(1.94, 38.70) = 19.49$, $p < .001$). Post hoc analyses determined the -60º through 0º phase relations to yield distinct differences from the other coordination patterns (see Table 5A1a).

Unsurprisingly, the significant post hoc differences for the -60º, -30º and 0º phase relations are observed in higher frequencies in the histogram data, with visual inspection indicating a pronounced -30º phase attraction for the lateral direction, and a lesser pronounced attraction to the same phase relation in the longitudinal direction. This phase relation represents a marginal lead-lag association with the ball leading the defenders within their respective cycles.

5.4.3. Coordination dynamics between the attackers and ball

Similarly, figure 5.2. (lower panels) report the relative phasing frequency histograms for both directions obtained from all observations of attackers and ball. Analysis of variance yielded main effects for relative phase, $F(5.28,105.69) = 23.77$, $p < .001$, and displacement, $F(1,20) = 105.64$, $p < .001$, as well as a significant interaction, $F(3.94,78.73) = 4.54$, $p < .01$. Post hoc analyses of the relative phase data reported significant differences between phase values, most noticeably between the -60º through 60º phase values and those of -150 º through -210º (see Table 5A1b). (Note. 150º and -210º denote the same phase relation because of the circular statistics used to express relative phase.)

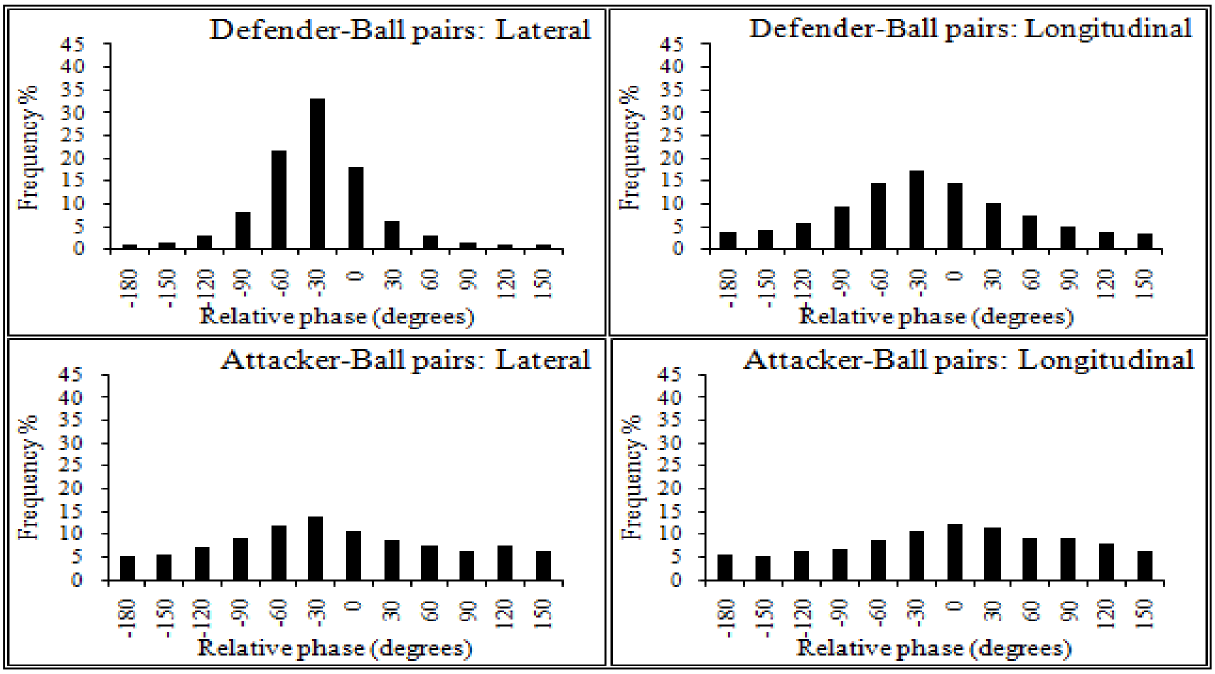

Figure 5.2. Relative phase between defenders/attackers and ball in lateral and longitudinal direction: Upper panels – Frequency histograms of all defenders and ball from all trials. Lower panels – Frequency histograms of all attackers and ball from all trials

Visual inspection of the relative phase histogram data further demonstrated weak attraction s towards in-phase in both directions. Weak phase attractions between the attackers and ball notwithstanding, ANOVAs for relative phase and team produced main effects for relative phase in both lateral, $F(1.81,36.24) = 50.19$, $p < .001$, and longitudinal directions, $F(3.10,61.99) = 46.46$, $p < .001$ as well as significant interactions, $F(1.50,30.06) = 27.44$, $p < .001$, and $F(3.29,65.76) = 20.04$, $p < .001$, respectively. Post hoc analyses of relative phase in both lateral (Table 5A2a) and longitudinal (Table 5A2b) directions determined significant differences between the phase ranges -90º through 30º (for lateral) and -60º through 30º (for longitudinal) as compared with the -120º through -300º values (i.e., -180º, -150º, -120º, -90º, 60º, 90º, 120º and 150º).

5.4.4. Intra team coordination – defending dyads

The relative phase histogram for the defending dyads revealed strong in-phase attraction in both directions (upper panels, figure 5.3.) with weaker phase attractions again noted for the longitudinal direction. From ANOVA, a main effect for relative phase, *F*(1.28,25.53) = 42.72, *p* < .001, and significant interaction were observed, *F*(1.68,33.61) = 28.99, *p* < .001. Post hoc analyses determined that the majority of significant pair wise differences were detected between the -60º through 30º and -180º through 300º phase ranges (Table 5A3a).

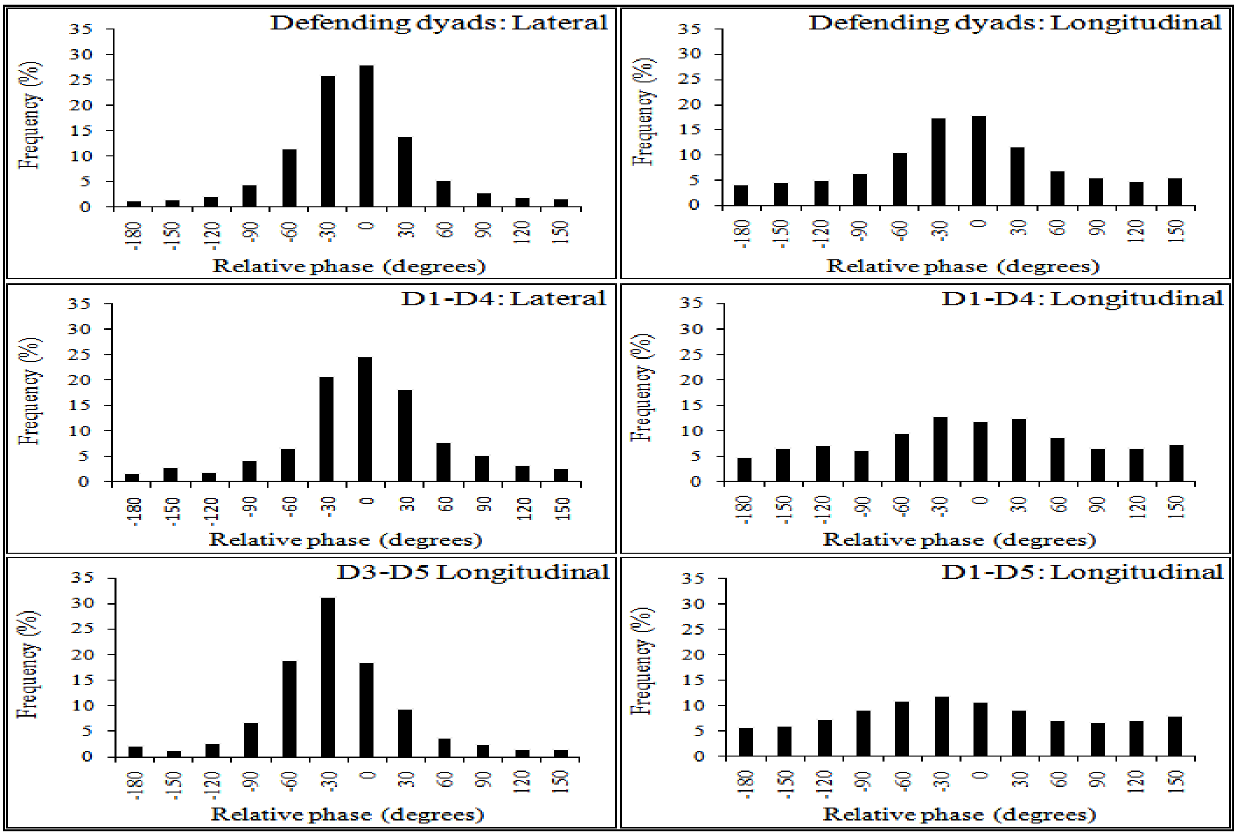

Figure 5.3. Relative phase between defending dyads in lateral and longitudinal direction: Upper panels – Frequency histograms of all defending dyads from all trials; Middle panels – Frequency histograms of a single defending dyad in lateral and longitudinal direction from a single trial; Lower panels – Frequency histograms of single defender–goalkeeper dyads from single trials in the longitudinal direction.

As noted, the defending dyads produced strong attractions to in-phase in the lateral direction and weaker attractions in the longitudinal direction. Indeed, all defending dyads produced strong in-phase attractions, or thereabouts, in the lateral direction (middle left panel, for example) whereas not all defending dyads demonstrated in-phase attractions in the longitudinal direction (middle right panel, for example). Specifically, the following dyads demonstrated strong in-phase attractions in the longitudinal direction (D1-D2, D2-D3, D2-D4, D2-D5 and D3-D5 – lower left panel) and the remaining dyads tended to approximate flat relative phase distributions with no evident attractions to preferred phase relations (D1-D3, D1-D4 – middle right panel, D1-D5 – lower right panel, D3-D4 and D4-D5).

The goalkeeper (D5) occupies a specialized playing position. As with the general findings, the defender-goalkeeper dyads demonstrated strong in-phase attractions in the lateral direction whereas the phase relations for the longitudinal displacements varied with different defenders. Strong -30º phase relations with the goalkeeper were maintained by players D2 and D3 (lower left panel), the offset from in-phase being attributed to the goalkeeper leading the outfield defender by a one-twelfth cycle, whereas approximations of flat phase distributions with the goalkeeper were observed for players D1 (middle right panel) and D4. These different results are attributed to the particular defensive responsibilities of the different playing positions. See figure 5.1. for general reference regarding the playing positions of the defenders, and the attackers who follow next.

5.4.5. Intra team coordination – attacking dyads

Unlike the defending dyads, the relative-phase histogram data for the attacking dyads from all trials demonstrated weak attractions for both lateral and longitudinal directions (upper panels, figure 5.4.). Even so, the main effect for relative phase was significant, $F(4.01,80.25) = 4.98, p < .001$, as was the interaction, $F(3.51,70.13) = 4.68, p < .01$, although post hoc analyses detected few significant differences between relative phase values (Table 5A3b).

The intra-team coordination phasing between attackers is much more varied than for the defenders. Analysis of variance with team as the second factor yielded main effects for relative phase in both lateral, $F(1.44,28.79) = 43.87, p < .001$, and longitudinal directions, $F(2.85,56.95)$

= 23.54, *p* < .001. Moreover, a significant effect for team was produced in the lateral direction, *F*(1,20) = 166.83, *p* < .001, but not the longitudinal direction. Similarly, a significant interaction was observed in the lateral direction, *F*(1.45,29.04) = 30.37, *p* < .001, and a significant interaction in the longitudinal direction was approached but not obtained, *F*(3.46,69.41) = 2.51, *p* = .058. Once again, post hoc analyses of relative phase in the lateral direction reported significant differences between the -60º through 30º and the -180º through 300º phase ranges (Table 5A4a). Fewer differences were observed for the longitudinal direction, with significant findings between the -60º and 0º phase range and remaining phase values (Table 5A4b).

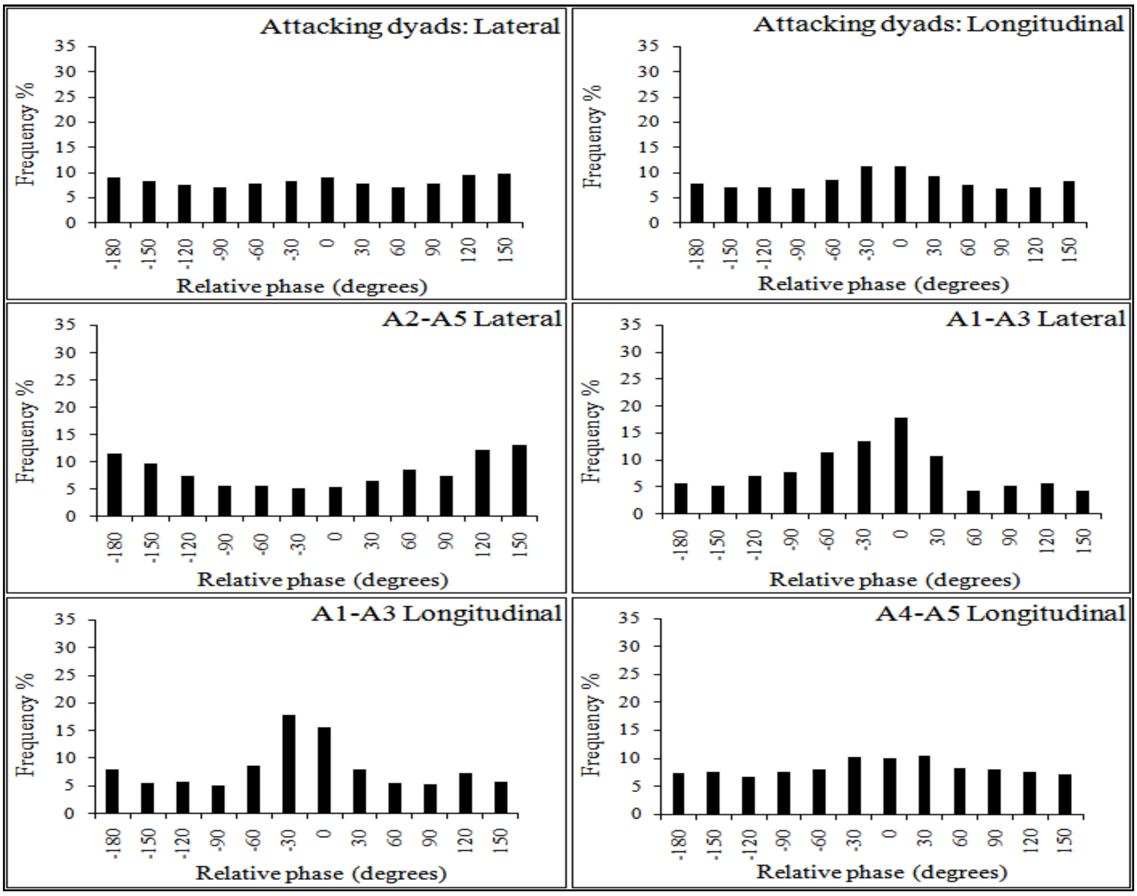

Figure 5.4. Relative phase between attacking dyads in lateral and longitudinal direction: Upper panels – Frequency histograms of all attacking dyads from all trials; Middle panels – Frequency histograms for single attacking dyads from single trials in the lateral direction; Lower panels – Frequency histograms for single attacking dyads from single trials in the longitudinal direction.

Subsequent investigation of individual dyads indicates different phase attractions for different dyads. In the lateral direction, general attractions to anti-phase were observed for the following dyads (A2-A3, A3-A4 and A2-A5 – left middle panel) whereas, in contrast, the A1-A3 dyad (right middle panel) demonstrated a reasonably strong in-phase attraction. There were no obvious phase attractions for the remaining attacking dyads. In the longitudinal direction, the following dyads (A1-A2, A1-A3 – lower left panel, A1-A4, A1-A5 and A3-A5) demonstrated attraction towards in-phase whereas the remaining dyads exhibited no preferred phase relations whatsoever (lower right panel, for A4-A5 example). In addition, note the strong attraction to in-phase, or thereabouts, for the A1-A3 dyad for both directions.

5.4.6. Inter-team coordination – defender-attacker dyads

The relative phase histograms for the defender-attacker dyads demonstrated weak attraction towards in-phase for both lateral and longitudinal displacements (figure 5.5., upper panels). Analysis of variance yielded main effects for relative phase, $F(3.06,61.14) = 45.91$, $p < .001$ and displacement, $F(1,20) = 13.70$, $p < .001$, but the interaction was not significant. Post hoc analyses reported significant relative phase differences between -60º through 0º and -90 º through -300º (Table 5A5).

The weak phase attractions in both directions are marked by considerable variability produced by the large number of attacker-defender dyads (N = 25). Select examples from a given trial are presented for the D4-A2 dyad (middle panels), and the D4-A4 dyad (lower panels). The strongest in-phase attractions, or thereabouts, in both lateral and longitudinal directions were observed for those defender-attacker dyads comprising direct opponents identified from playing position (e.g., D1-A1, D2-A2, etc.).

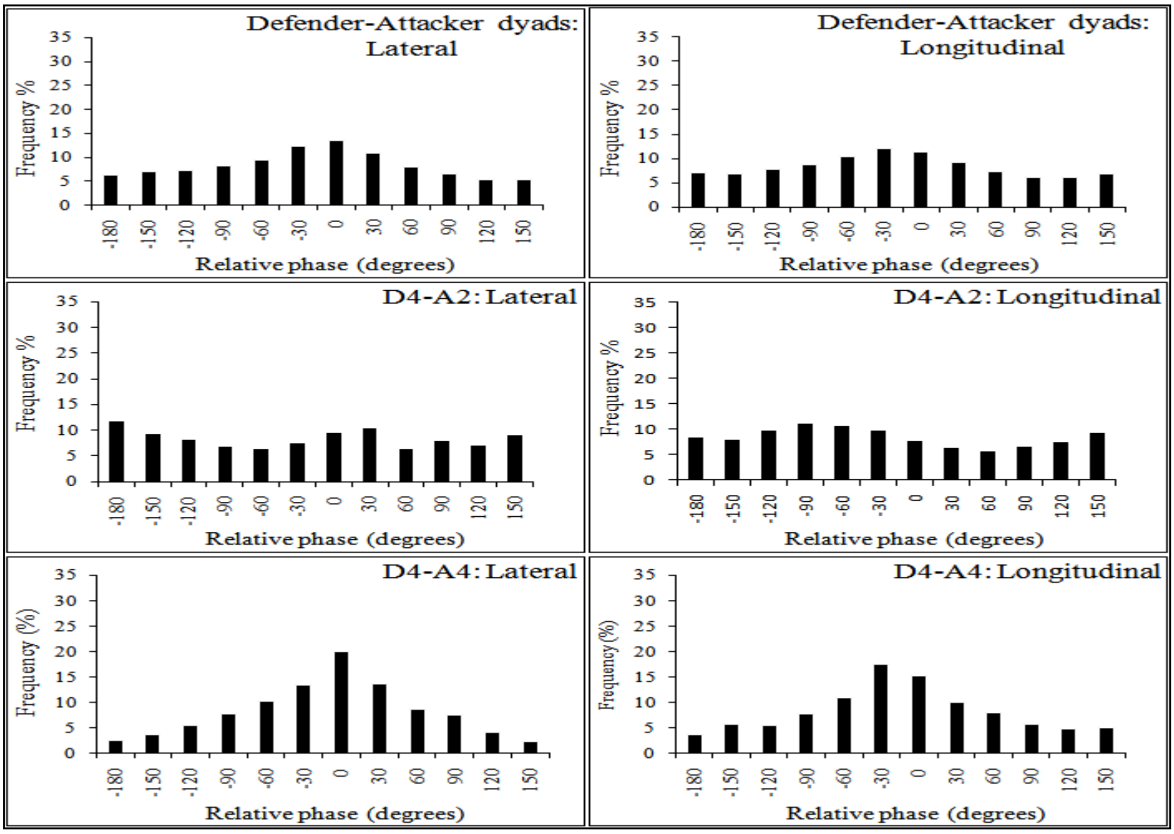

Figure 5.5. Relative phase between defender-attacker dyads in lateral and longitudinal direction: Upper panels – Frequency histograms of all defender-attacker dyads from all trials; Other panels – Frequency histograms for single defender-attacker dyads with different defenders.

5.5.Discussion

The aim of this investigation was to identify phase attractions between the movement kinematics of players and ball and between players themselves in 5-vs-4+GK futsal game practice. The nature of game sports means that the ball is an integral component of futsal game behavior and phase attractions between players and ball indeed demonstrate the ball dynamics as an important constraint, as predicted. In-phase attractions between players were reported with stronger attractions between defenders than attackers, as well in the lateral direction as opposed to the longitudinal one. These latter findings are opposite to the results obtained from investigations of basketball which reported stronger in-phase attractions for playing dyads in the longitudinal direction (Bourbousson et al., 2010a). These differences between the two investigations might be explained, in part, by the evident differences between basketball and futsal in general, as well as by the different playing conditions investigated (5-vs-5 in basketball, 5-vs-4+GK in futsal) and the different defending strategies used ("one-on-one" marking in basketball, zonal marking in futsal). These considerations of game context would be expected to constrain the types of phase relations produced in sports behavior (McGarry et al., 2002).

5.5.1. Ball dynamics

In the 5-vs-4+GK context, the ball dynamics demonstrated larger lateral displacements than longitudinal displacements (not shown), a result likely explained by virtue of the sports task under investigation. Specifically, a zonal defending strategy under 5-vs-4+GK conditions requires the outfield defenders to withdraw towards, and so protect, the region in front of the defending goal. In so doing, the defenders willingly permit the attackers increasing space in regions that are further from the defending goal, for obvious reasons. From the perspective of the attacking team, the attackers must try to generate goal shooting opportunities by opening lateral space with a view to penetrating the principal space that the zonal defending team is seeking to guard. This game behavior results in varying dynamic phase relations between players and ball, and between players, in both lateral and longitudinal directions.

5.5.2. Coordination dynamics between player-ball pairs

Strong -30º phase attractions between defenders and ball were reported for both lateral and longitudinal directions, particularly the former (figure 5.2., upper panels). Similar phase attractions in the lateral (-30º) and longitudinal (0º) directions were reported for the attackers too, albeit to lesser extents indicating weaker phase couplings for these data (figure 5.2., lower panels). These different results for the defenders and attackers are attributed to the contrasting aims of the two teams, namely that of preventing and scoring goals and the different strategies used as a means of achieving these separate objectives. Given that the ball is central to both teams achieving their specific objectives, it follows that the ball dynamics must necessarily constitute an important constraint on game behavior. This reasoning is supported in the general observation of stronger phase couplings between players and ball than produced between players themselves. Since the ball serves to constrain the relations between players in pursuit of their collective aims, and as this investigation is the first to address this particular issue, we propose that the kinematic relations between players and ball be afforded increased attention in future research on team sports behaviors.

The weaker phase attraction to the ball for the attackers is denoted by increased phase variability, a feature of meta-stable dynamical systems that promote the likelihood of system transitions between different regions of varying stabilities (Kelso & Engstrøm, 2006).Increased phase variability is furthermore consistent with the collective aim of the attacking team seeking to create spaces within otherwise contained dynamic game configurations. In contrast, the collective aim of the defending team is achieved when game behaviors remain contained until ball possession is regained. Thus, reduced variability and stronger attractions to certain phase relations for the defending team, and, conversely, increased variability and weaker phase attractions for the attacking team, are explained by virtue of the competing game objectives of the two teams. Of course, since the aims of the defending and attacking teams are dependent on ball possession, the aims of both teams will necessarily change with changes in ball possession.

This investigation has revealed dynamical linkages between players and ball from which we deduce that attackers and defenders integrate ball kinematics information to coordinate actions with teammates and opponents. Practice conditions therefore should be designed to represent these key informational properties of game behavior so as to facilitate the perceptual abilities of players to make use of this information to produce successful actions (Araújo & Davids, 2009).

5.5.3. Intra-team coordination – defending and attacking dyads

The data representing the intra-team coordination of defenders and attackers reported in-phase attractions. Once again, the attackers demonstrated considerably weaker phase attractions than the defenders, with the increased phase variability offering greater behavioral possibilities for change. These weaker phase attractions may be considered in terms of the attacking players advancing their common objectives by processes of active exploration (Davids et al., 2003), shared objectives that might be considered as additional social constraints that help shape game behavior (Marsh et al., 2006).

McGarry and colleagues (2002) posited information couplings within and between playing dyads as the basis for dynamic game behavior. This plasticity of game behavior, from the individual to the collective, is important as it allows for game objectives to be reached in functional ways (Davids et al., 2003). Thus, the attackers try to disrupt the defensive structure by exploring the various dynamical relations whereas the defenders couple themselves with the ball and teammates to maintain various positional relations, with the ball, with each other, and with the goal area being defended. These differences between defenders and attackers, and the respective associations of defenders and attackers with the ball, highlight the functional collective order that emerges as a result of the various cooperating and competing drives of individuals and teams as they pursue their game objectives (Passos et al., 2008).

5.5.4. Positional influences on the playing dyads

The positions to which the players are assigned influences the phase relations of the playing dyads, presumably by virtue of the responsibilities and duties assigned to these positions. For the defending dyads, the left (D2) and right-wing (D3) players developed a strong in-phase coupling with the goalkeeper (D5) in the lateral direction. This result is attributed to the defensive aim of maintaining a compact organized structure with respect to the ball and goal area being defended. The target (D1) and pivot (D4) defenders however produced no such evidence of attraction to specific phase relations with the goalkeeper (D5), perhaps because their main objective was to guard space afforded to attackers in the central position of the field, regardless of ball location. Moreover, the pivot defender (D4) using zone defense is required to apply space-time pressure on both the left (A4) and right (A5) attacking wing-players, depending on game context at any instant, thus reducing the likelihood of phase attraction with the goalkeeper.

For the attacking dyads, an in-phase relation between the pivot (A1) and right flank (A3) players was observed whereas the left (A4) and right (A5) wing players produced an anti-phase relation. The same phase attraction between wing players of the attacking team in basketball was reported by Bourbousson, et al. (2010a), with these authors attributing this finding to the wing players combining to contract and expand lateral space in tandem. These results may be explained by considering a variety of factors, including the responsibilities assigned to playing positions, the type of game strategies used, the context of the unfolding game demands, and the abilities of individual players (Davids et al., 2008).

5.5.5. Inter-team coordination – defender-attacker dyads

Stronger in-phase attractions between defender and direct opponent based on playing position were observed than those with other opponents, the exception being the pivot player for the defending team (D4). This exception is explained by the defending team adopting a zonal defensive strategy in a 5-vs-4+GK context in an effort to counter being short-handed, with D4 being tasked with defending against both A4 and A5 depending on game conditions.

The phase relations between players and ball, between players from the same team, and between players from opposing teams, subscribe to the theoretical principles of dynamical systems that explain coordinated game behavior as a self-organizing consequence of information exchanges (McGarry et al., 2002). The emerging coordination dynamics are furthermore constrained by the aims of the players and teams (Araújo et al., 2006; Passos et al., 2008), and the different phase relations observed result from active processes of dynamic exploration as players and teams seek to accomplish their game objectives. Thus, variability may be an important means by which collective objectives such as scoring goals are reached. In this report, we interpret the movement kinematics of the ball and players, and their varied phase relations, in terms of breaking and maintaining symmetry designed to enhance the competing prospects of the attacking and defending teams achieving their principal game objectives, respectively (McGarry et al., 2002). In sports practice, coaching sessions should thus be geared to advancing individual and collective decision-making and action behaviors by promoting understanding of performance constraints using processes of self-discovery learning rather than means of didactic instruction (Davids et al., 2003; Renshaw, Davids, Shuttleworth, & Chow, 2009).

In sum, the phase relations between the players and the ball, and the playing dyads themselves, demonstrated different results for the attacking and defending teams because of the different game objectives. To achieve these respective aims the attacking players generally demonstrated increased variability in the phase relations of whom they were coupled, including the ball, whereas the defending players demonstrated less variability. From this result, we interpret variability of the phase relations as being important for the attacking players who seek to disturb the stabilized in-phase relations that the defenders look to maintain.

5.5.6. The 5-vs-4+GK futsal sub-phase: Final comments

For reasons noted earlier, the 5-vs-4+GK coordination dynamics reported in this investigation were produced in game practice on the attacking half of the pitch, although a subsequent rule change now in effect. This rule change notwithstanding, we expect the findings reported here to generalize to game behavior under the new game rules as most 5-vs-4+GK game behavior still takes place in the attacking half pitch, a natural consequence of the competing priorities of the attacking and defending teams. In addition, the coordinated (relative) movements of the players and ball would not be expected to change much by virtue of the rule change. On the same reasoning however, different coordination patterns might be expected for game behaviors produced under typical game conditions, that is when both teams contain four outfield players plus goalkeeper, as compared to the less balanced 5-vs-4+GK sub-phase considered in this report. Further research is required to inform on these issues.

5.6.References

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5.7. Appendix

Table 5A 1 - Post hoc results for (a) the defenders and ball and (b) the attackers and ball.

	(a) Defender-ball													(b) Attacker-ball											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1	—		*	*	*	*	*						1	—				*	*	*	*	*			
2		—		*	*	*	*						2		—			*	*	*	*	*			
3	*		—		*	*	*				*	*	3			—			*	*					
4	*	*		—	*	*					*	*	4				—								
5	*	*	*	*	—			*	*	*	*	*	5	*	*			—							
6	*	*	*	*		—	*	*	*	*	*	*	6	*	*	*			—			*			*
7	*	*	*			*	—	*	*	*	*	*	7	*	*	*				—					*
8					*	*	*	—					8	*	*						—				*
9					*	*	*		—				9	*	*				*			—			
10					*	*	*			—			10										—		
11			*	*	*	*	*				—		11											—	
12			*	*	*	*	*					—	12						*	*	*				—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * p < 0.001.

Table 5A 2 - Post hoc results for attacker-defender and ball in (a) the lateral direction and (b) the longitudinal direction.

	(a) lateral direction													(b) longitudinal direction											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
A	—			*	*	*	*	*					A	—				*	*	*	*				
B		—		*	*	*	*	*					B		—			*	*	*	*				
C			—	*	*	*	*						C			—		*	*	*					
D	*	*	*	—	*	*				*	*	*	D				—	*	*	*					
E	*	*	*	*	—			*	*	*	*	*	E	*	*	*	*	—				*	*	*	*
F	*	*	*	*		—	*	*	*	*	*	*	F	*	*	*	*		—			*	*	*	*
G	*	*	*			*	—	*	*	*	*	*	G	*	*	*	*			—		*	*	*	*
H	*	*			*	*	*	—				*	H	*	*						—			*	*
I					*	*	*		—				I					*	*	*		—			
J				*	*	*	*			—			J					*	*	*			—		
K				*	*	*	*				—		K					*	*	*	*			—	
L				*	*	*	*	*				—	L					*	*	*	*				—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * p < 0.001.

Table 5A 3 - Post hoc results for (a) defending dyads and (b) attacking dyads.

	(a) defending dyads												(b) attacking dyads											
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
1	—				*	*	*	*																
2		—			*	*	*	*																
3			—		*	*	*	*																
4				—	*	*	*	*																
5	*	*	*	*	—		*			*	*	*												
6	*	*	*	*		—			*	*	*	*	No significant data											
7	*	*	*	*			—		*	*	*	*												
8	*	*	*	*	*			—	*	*	*	*												
9		*				*	*	*	—	*	*													
10					*	*	*	*	*	—														
11					*	*	*	*	*		—													
12					*	*	*	*				—												

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * $p < 0.001$.

Table 5A 4 - Post hoc results for attacking and defending dyads in (a) the lateral direction and (b) the longitudinal direction.

	(a) lateral direction													(b) longitudinal direction											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1	—				*	*	*	*					1	—											
2		—			*	*	*	*					2		—			*	*						
3			—		*	*	*	*					3			—		*	*						
4				—	*	*	*	*					4				—	*	*	*					
5	*	*	*	*	—					*	*	*	5				*	—						*	
6	*	*	*	*		—			*	*	*	*	6		*	*	*		—			*	*	*	
7	*	*	*	*			—		*	*	*	*	7		*	*	*			—		*	*	*	*
8	*	*	*	*				—	*	*	*	*	8								—	*		*	
9						*	*	*	—				9						*	*	*	—			
10					*	*	*	*		—			10						*	*			—		
11					*	*	*	*			—		11					*	*	*	*			—	
12					*	*	*	*				—	12							*					—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * $p < 0.001$.

Table 5A 5 - Post hoc results for attacker-defenders dyads.

	1	2	3	4	5	6	7	8	9	10	11	12
1	—				*	*	*					
2		—			*	*	*	*				
3			—		*	*	*					
4				—	*	*	*				*	
5	*	*	*	*	—					*	*	*
6	*	*	*	*		—			*	*	*	*
7	*	*	*	*			—		*	*	*	*
8		*						—	*	*	*	*
9						*	*	*	—		*	
10					*	*	*	*		—		
11				*	*	*	*	*			—	
12					*	*	*	*				—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * $p < 0.001$

6. Spatiotemporal Coordination Patterns in Futsal are Guided by Informational Game Constraints

6.1.Abstract

The aim of this study was to investigate the space-time movement patterns of futsal teams in game practice. To this end, the lateral and longitudinal displacements of the ball and both teams, as well as their kinematics expressed in angles and radial distances from the centre of goal, were obtained and subjected to relative phase analysis. The results demonstrated stronger phase relations with the ball for the defending team than the attacking team. Moreover, the phase relations between the ball and the teams demonstrated complementary associations with each other. For example, when one team demonstrated stable phasing with the ball, the other team demonstrated unstable phasing, and when one team produced in-phase relations the other team sometimes produced anti-phase. The strongest in-phase attractions were observed using angles to measure the associations between the defending team and ball, indicating the position of ball and goal location as key informational constraints for futsal game behavior.

6.2.Introduction

Team sports behaviors are predicated on the competing aims of the two teams, with the attacking team looking to keep ball possession and make a score (e.g., a goal, a basket, a point, etc.) and the defending team seeking to protect against a score and win ball possession. In this context, the playing behaviors that characterize a given sports contest are proposed to emerge as a self-organizing consequence of the cooperating and competing coordination tendencies exhibited by players (McGarry et al., 2002). The reader is referred to Kean (2000) for examples of cooperation and competition from movement information available to dyads in social contexts.

Player and team behaviors aimed towards specific objectives are generated from spontaneous, self-organizing, localized, dynamical interactions operating under a variety of individual, task, and environmental constraints (Araújo, Davids, Bennett, Button, & Chapman, 2004; Davids et al., 2008; Davids et al., 2001). On this perspective, the changing configurations of players and teams is interpreted as an emerging process resulting from changing game constraints (Araújo et al., 2006; Passos et al., 2008), with the information exchanges between dyads, from individual players through player collectives, proposed as the basis for the patterned sports behaviors observed in game competition (McGarry et al., 2002). In team sports, the behavioral patterns may be investigated at different levels of analysis, from interactions between individual players (Bourbousson et al., 2010a) to interactions between collectives of players, for example interactions between two teams (Bourbousson et al., 2010b; Frencken & Lemmink, 2008; Lames, Erdmann, & Walter, 2010).

The idea of game behavior as a self-organizing dynamical process has been investigated in various sports (Araújo et al., 2006; Davids, Araújo, & Shuttleworth, 2005; McGarry et al., 2002; Palut & Zanone, 2005; Passos et al., 2009; Reed & Hughes, 2006). Previous research of game behavior used relative phase to assess the spatiotemporal coordination patterns between teams (Bourbousson et al., 2010b; Lames et al., 2010), with findings demonstrating general tendencies of synchronized displacements in the lateral (i.e., side-to-side) and longitudinal (i.e., forward-backward) directions, particularly the latter. As noted previously, these coordinated team dynamics are the hypothesized result of information exchanges between players and teams acting under game constraints (Marsh et al., 2006; McGarry et al., 2002). Given the primary game objectives of team sports noted at the outset of this report, the location of the ball with respect to the scoring targets (e.g., basketball hoops, football goals) constitute important constraints when considering dynamical game behaviors of players and teams, with the ball furthermore providing a principal means for information exchange between players and teams (McGarry, 2009). In this study, we advance upon previous research by accounting for these important game constraints when investigating team dynamics produced in futsal game practice.

Futsal is a FIFA regulated five-a-side indoor association football game played on a 40 x 20 meters hard surface court, or pitch. In futsal competition, a common game strategy is for the trailing team towards the end of a game to substitute the goalkeeper for an extra outfield player when in possession of the ball. This game strategy, hereafter referred to as 5-v-4+GK, gives the trailing team a numerical advantage of outfield players, and is designed to increase the likelihood of generating goal scoring opportunities. In the final four of the UEFA Futsal Cup in Lisbon, 2010, half of the goals scored in the last five minutes occurred using this 5-v-4+GK game strategy, thereby demonstrating its importance to futsal competition.

In this report, we extend on earlier investigation of the dynamical behaviors observed between players and ball, and between players themselves, in 5-v-4+GK futsal game practice (Travassos et al., In press). As with player behaviors, we expect the team behaviors produced in 5-v-4+GK futsal game practice to conform to dynamical self-organizing principles, for the reasons outlined by McGarry et al. (2002). Furthermore, we will account for game context in this investigation by considering the positions of the ball and teams with reference to goal location. As proposed earlier, the expectation is that the ball dynamics and goal location are important constraints on game behavior, and, as such, are deserving of attention for advancing understanding of game behavior.

6.3.Method

This study was approved by the research ethics committee of the Faculty of Human Kinetics, Technical University of Lisbon, and followed the guidelines specified by the American Psychological Association.

6.3.1. Participants

Fifteen male senior players of the National Futsal University Team in Portugal were invited to participate in this study (mean value 23.25 years, s = 1.96 years), with each player providing informed consent before data collection.. Participants were grouped into three teams of five players each.

6.3.2. Data collection

Nine 5-vs-4+GK game condition practice sessions of five minutes duration were undertaken, with each team competing against each other in round robin fashion on three separate occasions. Thus, each team played two consecutive game sessions interspersed with five minutes of rest to offset fatigue (Castagna et al., 2009). The practice sessions were performed according to the Official Futsal Rules (FIFA) with the defending (4+GK) and attacking (5) teams trying to prevent and score goals, respectively. The nine practice sessions were recorded at 25 Hz using a digital camera placed in the superior plane and positioned 45º to the middle field line. Thus, all the movements of the ball and players were made available for analysis.

6.3.3. *Data analysis*

From the available data, the movement trajectories of ball and players from 21 trial sequences ending with a shot at goal were digitized in slow video by the first author using TACTO software (see Duarte et al., 2010). The virtual coordinates obtained from the digitization were transformed to pitch coordinates using a bi-dimensional direct linear transformation method (2D-DLT) (see Duarte et al., 2010; Fernandes & Malta, 2007), before being subjected to a 6 Hz low pass filter (Winter, 2005).

Two separate coordinate systems were used for data analysis. Zero data were assigned to the bottom left corner of the half-pitch using Cartesian coordinates, and zero data assigned to the centre of the goal line using polar coordinates (see Figure 6.1.). In both coordinate systems, position of the ball and the geometric centre of both teams, obtained from the arithmetic mean of the five players per team, were obtained for all time samples, thereby yielding measures of lateral and longitudinal displacements (Cartesian coordinates), and angles and radial displacements (polar coordinates). These time series data, which contain well-expressed peaks and troughs, were then subjected to relative phase analysis using Hilbert transform (Palut & Zanone, 2005; Rosenblum, Pikovsky, & Kurths, 2004).

The relative phase quantifies the position relations between two sinusoidal signals by measuring the phase differences between signals in their respective cycles. For example, in-phase (0º) represents signals at the same point in their respective cycles, and anti-phase (180º) denotes signals that are a half-phase displaced from each other, with other phase relations between in-phase and anti-phase likewise expressed with values between 0º and 180º (or between 180º and 360º). The relative phase data were inspected using frequency phase histograms and phase attractions noted from observations of peak frequency (Palut & Zanone, 2005). Also, the relative phase frequency data were subjected to a 12x2 mixed model ANOVA with a within-subject factor on relative phase (-180º, -150, ... 150º), and a between-subject factor being either direction (lateral, longitudinal), team (attack, defense) or polar position (radial distance, angle), as appropriate. The ANOVAs were subjected to Mauchly's sphericity test and, when necessary, the Greenhouse-Geisser correction procedure was used to adjust the degrees of freedom. Significant ANOVA results were followed up with Bonferroni post hoc analyses.

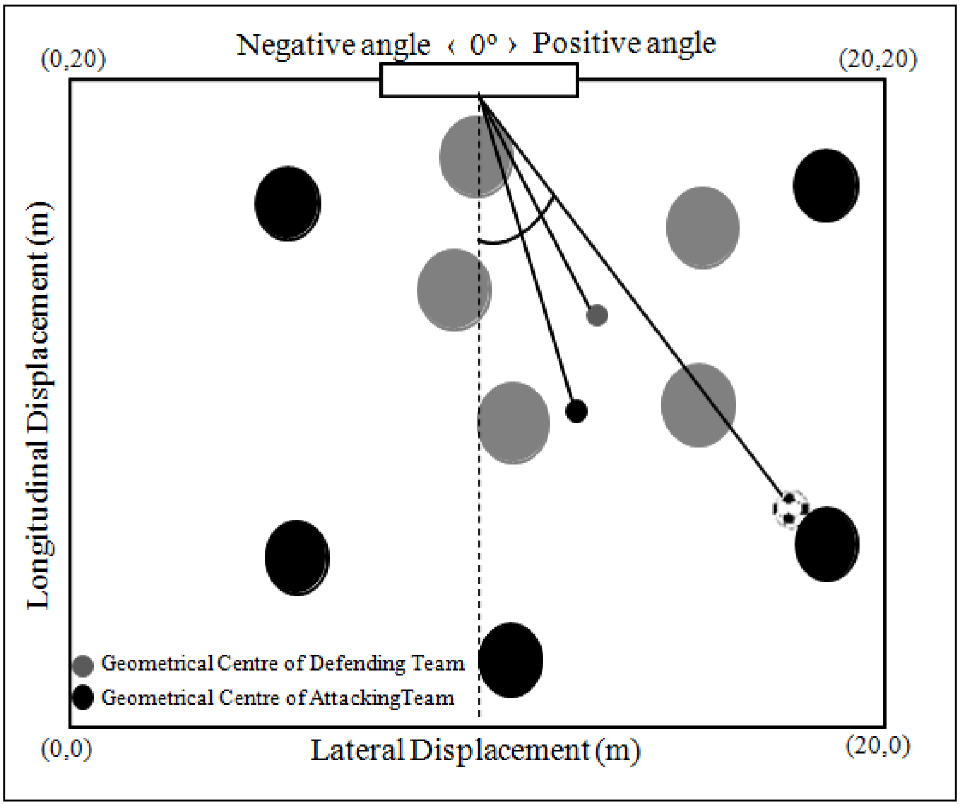

Figure 6. 1. - Half-pitch representation using Cartesian and polar coordinates of the players (large circles) and team geometric centers (small circles) and ball. The datum coordinates are located bottom left (Cartesian) and top middle (polar). The defending team is represented in grey and the attacking team in black.

6.3.4. Reliability

One of the 21 trials was selected at random and the data trajectories of the ball and players re-digitized by the first author. The data were assessed for accuracy and reliability using technical error of measurement (TEM) and coefficient of reliability (*R*), respectively (Goto & Mascie-Taylor, 2007). The intra-TEM yielded values of 0.25 meters (3.65%), 0.19 meters (1.75%) and 0.24 meters (2.36%) for attackers, defenders and the ball, respectively. These results indicate good accuracy, and therefore agreement, between trials. The coefficient of reliability produced data for the attackers *(R*= .97), defenders (*R*=.96) and ball (*R*=.99) demonstrating good reliability between measurements.

6.4. Results

6.4.1. Cartesian coordinates

6.4.1.1. Phase relations between the ball and the defending team.

Two-way ANOVA of the phase relations revealed a main effect for relative phase, $F(1.47, 29.30) = 70.43$, $p < .001$, but not for direction, and a significant interaction between both factors, $F(1.67, 11.33) = 11.33$, $p < .001$). Post hoc analyses for relative phase determined the -90º through 0º phase relations to yield distinct differences from the other coordination patterns (see Table 6A1a). The phase relations demonstrated -30º attractions in both lateral and longitudinal directions, with stronger attractions observed for the lateral direction (upper panels, Figure 6.2.).

6.4.1.2. Phase relations between the ball and the attacking team.

Similar analysis on the phase relations between the ball and the attacking team again produced a main effect for relative phase, $F(3.29, 65.76) = 24.83$, $p < .001$, but not for direction, and a significant interaction between both factors, $F(3.32, 66.32) = 9.48$, $p < .001$).

Post hoc analyses for relative phase determined the -30º through 30º phase relations to yield distinct differences from the 120º through 210º phase relations (see Table 6A1b). (Note. -180º and 180º, and -150º and 210º, represent the same phase relations by virtue of the circular statistics.) The lateral and longitudinal directions produced phase attractions of -30º and 0º, respectively, although these attractions were much less pronounced as compared to those of the defending team (second panels, Figure 6.2.).

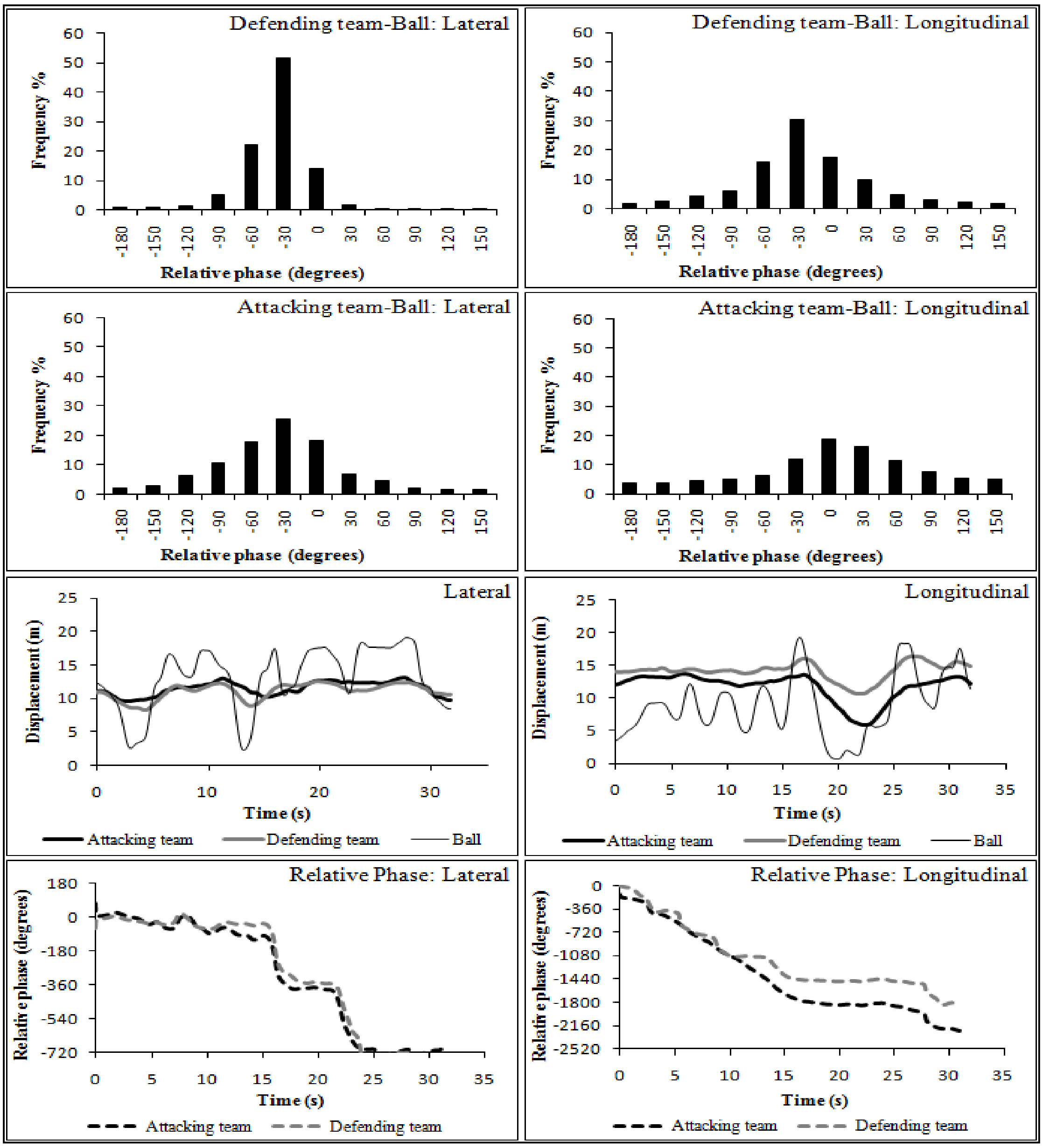

Figure 6. 2. - Relative phasing between the defending and attacking teams and ball for lateral (left panels) and longitudinal (right panels) directions: Upper panels - Frequency histograms for the defending team and ball; Second panels - Frequency histograms for the attacking team and ball; Third panels – Single trial displacement time-series of both teams and ball; Lower panels – Single trial relative phase dynamics of both teams and ball.

6.4.1.3. Phase relations between the ball and teams combined.

Two-way ANOVAs for relative phase and team produced main effects for relative phase in both lateral, *F*(1.63,32.54) = 43.74, *p* < .001, and longitudinal directions, *F*(3.51,70.22) = 34.18, *p* < .001, as well as significant interactions, *F*(2.15, 43.04) = 16.19, *p* < .001, and *F*(4.60, 91.90) = 21.90, *p* < .001, respectively, but no main effects for team. Post hoc analyses of relative phase in the lateral direction determined significant differences between the phase ranges -60º through 30º and most other phase values (Table 6A2a), and between -30º through 30º and most other values for the longitudinal direction (Table 6A2b).

Figure 6.2. also presents data from a single trial, the displacements of the ball and the two teams in both directions (third panels) together with their relative phasing (lower panels). The results demonstrate reasonably stable in-phase relations with the ball for both teams in the lateral direction, whereas in the longitudinal direction only the defending team maintains in-phase relations with the ball for the entire trial. In contrast, the attacking team produced unstable phase relations for the first half of the trial, as evidenced by the straight line with constant slope, before establishing a stable in-phase relation (-1800º) from the half-way mark onwards. (Note. The values -360º, -720º, and so on, represents in-phase by virtue of the circular statistics used to express relative phase).

6.4.1.4. Phase relations between the defending and attacking teams.

Statistical analysis of phase relations revealed a main effect for relative phase, $F(2.10, 42.07) = 35.70$, $p < .001$, but not for direction, and a significant interaction between both factors, $F(2.97, 59.40) = 4.15$, $p < .05$). Post hoc analyses of relative phase determined the -30º through 30º phase relations were significantly different from some of other coordination patterns (see Table A3). The phase relations demonstrated -30º attractions for the lateral direction and 0º attractions for the longitudinal direction (Figure 6.3.).

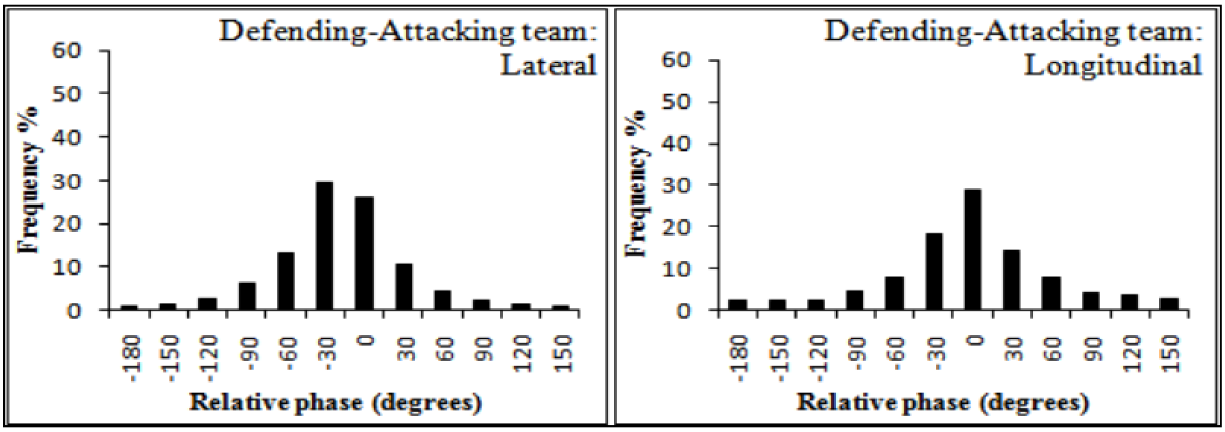

Figure 6. 3. - Frequency histograms depicting relative phase between the defending and attacking teams for the lateral (left panel) and longitudinal (right panel) directions.

Figure 6.4. presents the displacement data between the defending and attacking teams (upper panels), as well as between the defending team and ball (lower panels), together with their relative phasings. For both lateral and longitudinal directions, the results demonstrated stronger in-phase attractions for the defending team and ball than between the two teams, particularly so in the lateral direction. Moreover, increased phase attractions between the defending team and ball were accompanied by variability in the phasing relations between teams in lateral and longitudinal displacements (see boxes 1, 2 and 3, 4 on Figure 6.4.).

6.4.2. Polar coordinates

6.4.2.1. Phase relations between the ball and the defending team.

Two-way ANOVAs produced a main effect for relative phase, $F(1.30, 26.03) = 60.97$, $p < .001$, but not for “polar displacement” (angle, radial distance), and a significant interaction between both factors, $F(1.73, 34.58) = 6.11$, $p < .05$). Post hoc analyses for relative phase determined significant differences between the -30º through 30º phase relations and most other coordination patterns (see Table 6A4a). In-phase attractions were observed for both angle and radial distance, with stronger attractions observed for angles than for radius (upper panels, Figure 6.5.).

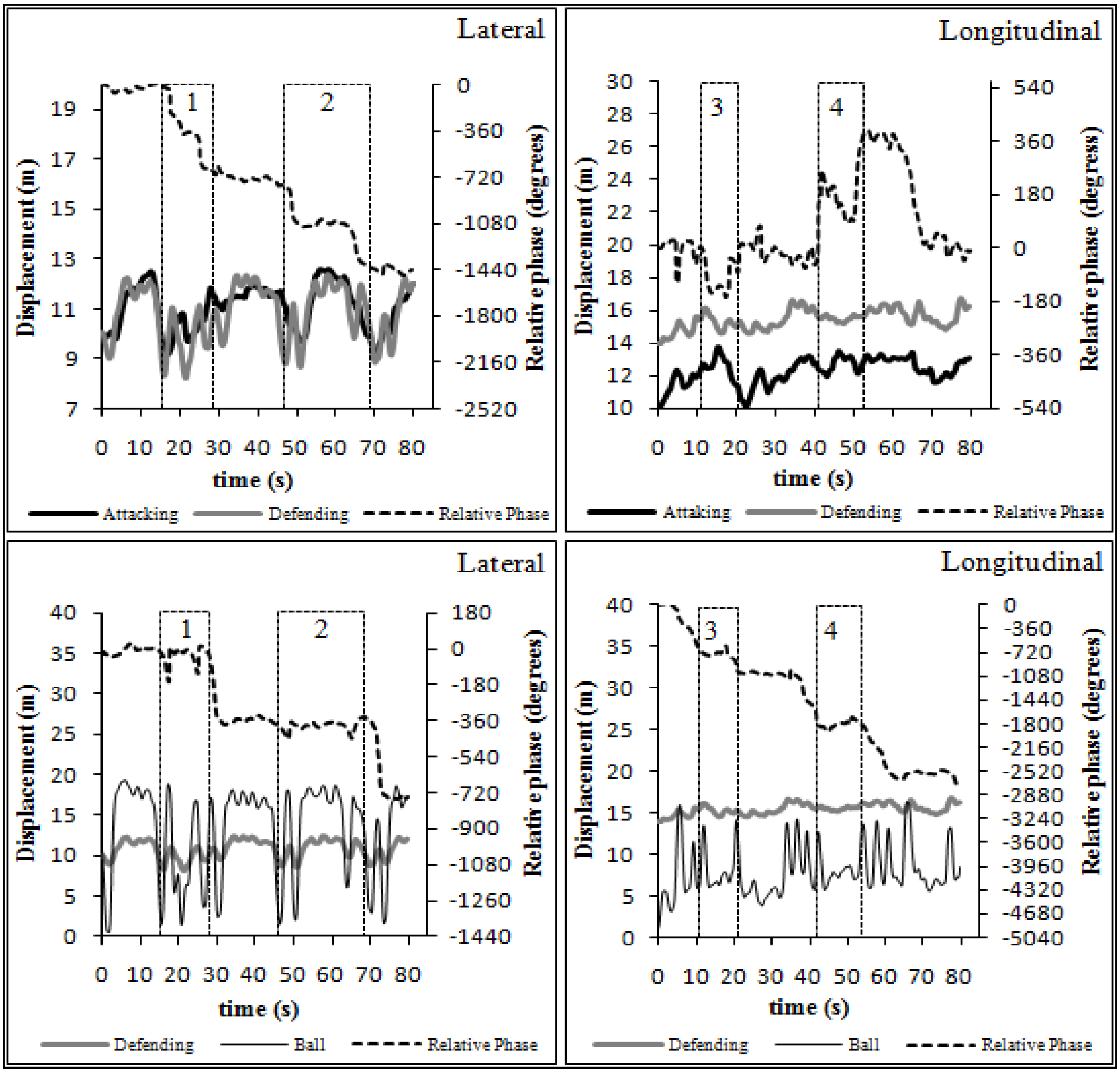

Figure 6. 4. - Relative phase between the defending and attacking teams (upper panels) and, the defending team and ball (lower panels). In all panels, the relative phase is represented using the black dashed line and the grey line represents the defending team. In the upper panel, the black line represents the attacking team. In the lower panels, the thin black line represents ball trajectory.

6.4.2.2.Phase relations between the ball and the attacking team.

Again, two-way ANOVAs revealed a main effect for relative phase, *F*(2.31, 46.18) = 27.90, *p* < .001, but not for polar displacement, and a significant interaction between both factors, *F*(3.11, 62.21) = 4.73, *p* < .05). Post hoc analyses produced significant differences between the -30º through 30º phase relations and some of other values (see Table 6A4b), with in-phase and 30º phase attractions observed for angles and radial distances, respectively (middle panels, Figure 6.5.). These attractions with the ball however were much weaker for the attacking team than those demonstrated by the defending team.

6.4.2.3. Phase relations between the defending and attacking teams.

Two-way ANOVAs reported a main effect for relative phase, $F(1.67, 33.47) = 25.73$, $p < .001$, but not for polar displacement, and no significant interaction. From post hoc analyses, significant differences were reported for -30º and in-phase and 30º phase values from some of the other coordination patterns (see Table 6A5), with -30º and in-phase attractions indentified for angle and radial distance, respectively (lower panels, Figure 6.5.).

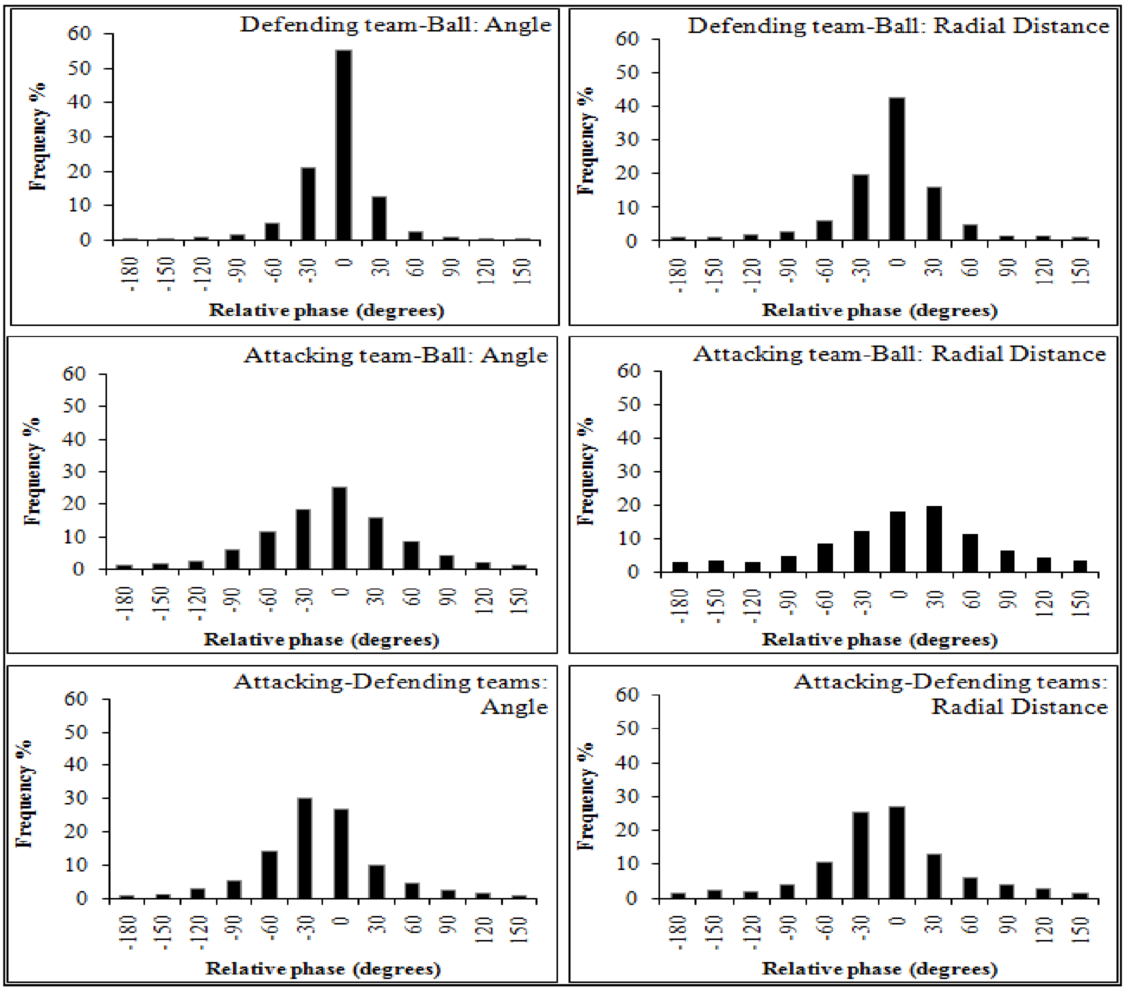

Figure 6. 5. - Relative phase between the two teams and ball using polar coordinates (angle and radial distance): Frequency histograms for the defending team and ball (upper panels); attacking team and ball (middle panels); defending and attacking teams (lower panels).

6.5.Discussion

The patterned behaviors observed are considered as emergent features of game behavior produced under various constraints, including the player configurations, the ball kinematics, and the goal being attacked and defended. Consideration of the competing aims of the two teams leads to a priori expectations of different associations with the ball, as both teams try to achieve their different game objectives. Indeed, despite similar in-phase attractions with the ball for both attacking and defending teams, markedly stronger attractions were produced by the defending team than the attacking team (see Figure 6.2.). This result is explained by the defending team striving to reduce possible goal scoring opportunities by maintaining a synchronous relation with the ball at all times, whereas the attacking team is seeking to increase the number of action possibilities for goal scoring opportunities by probing constantly the defensive structure. Thus, the attacking team explores continually the spatiotemporal relations that describe the game structure, with the express purpose of disrupting the defending team behaviour for generating goal attempts. This view is akin to the notion of perturbations that have been proposed to change the behavioural stabilities of a sports game (McGarry et al., 1999), as well as the notion of "functional variability" which describes the action possibilities available within biological systems (Davids et al., 2003). These action possibilities provide for adaptation within socio-biological that underscores the different coordination patterns that are essential for system functioning (Kelso & Engstrøm, 2006).

In a 5-vs-4+GK game situation, the defending team tries to counter the numerical outfield player advantage of the attacking team by using zone defense. This game strategy seeks to limit goal scoring opportunities by reducing the spaces afforded the attacking players in the region of the goal being defended. When successful, this game strategy results in collective synchrony between the defending team and ball, as indicated in the strong in-phase attractions reported previously.

Of note, stronger in-phase attractions of the defending team and ball were observed for the lateral direction than the longitudinal direction (see Figure 6.2.). This finding may be due to increased player displacements in the lateral direction, a result of the zonal strategy used to defend the goal. In general, the defending players may be more responsive to ball kinematics in the lateral direction, and less responsive in the longitudinal direction when doing so would draw them from the defensive zone, for example when the ball is being displaced backwards by the attackers and thus away from the goal (see Figure 6.4.). These general findings of varying phase attractions between the defending and attacking teams are consistent with the view that the ball dynamics, goal location and game objectives constitute important constraints on playing behavior.

In team sports like futsal, the attackers will attempt to fashion time and space by breaking synchrony with the defenders at opportune times whereas the defenders will try to restrict the time and space of the attackers by achieving synchrony with them, when possible (McGarry, 2005). These competing objectives produce varying complementary phase attractions. For example, increased phase attractions between the defending team and ball were accompanied by reduced attractions in the phasing relations between teams, as noted by increased phase variability (see boxes 1 and 2, Figure 6.4.). Also, when the defending team and ball produced in-phase coordination, the attacking team and ball demonstrated phase instabilities, with some attraction to anti-phase in some instances (see boxes 3 and 4, Figure 6.4.). These results demonstrate complementarity within the system whose coordination dynamics are restricted necessarily by the degrees of freedom available (Kelso & Engstrøm, 2006).

The game behaviours in sports competition emerges by players acting on the information flow available to them within system constraints such as game rules, game strategies, changing objectives, and so on (Araújo et al., 2006; Passos et al., 2008). Thus, the coordination dynamics between the defending team, attacking team and ball emerge from the functional information available, and the self-organising tendencies of the system. These suggestions are consistent with the results of Travassos and colleagues (In press) who analyzed the 5-v-4+GK game data at the level of playing dyads. That study reported stronger phase attractions for the player and ball dyads than for the playing dyads comprising the same team (see Figures 6.2. and 6.3.). In the present study, stronger phase attractions between the team and ball were observed than those between the players and ball reported by Travassos et al. (In press), a finding that is consistent with statistical considerations. From behavioral considerations, increased variability observed for the playing dyads may be the result of players continually engaging with their surrounds so as to produce functional adaptive behaviors at the team scale, as noted for other biological systems (Beek, Verschoor, & Kelso, 1997; Kelso & Engstrøm, 2006).

In this study, stronger in-phase attractions between the two teams in the lateral direction as opposed to the longitudinal direction were observed (see Figure 6.3.), results opposite to those reported previously for basketball (Bourbousson et al., 2010b) and small-sided soccer games (Frencken & Lemmink, 2008). These differences can be attributed to the different nature of the game conditions investigated and the different strategies used by the defending teams. (For basketball and soccer, the teams comprised of 5-v-5 and 4-v-4, respectively, with individual defending strategies used by both teams in both investigations.) These differences notwithstanding, the various team sports investigated report common properties that are predicted on theoretical underpinnings of dynamical self-organizing systems, as hypothesized by McGarry et al. (2002).

In considering the movement behaviors of players, teams and ball in regard to location on the field of play, the data were analyzed using polar coordinates. These coordinate data provided measures of direction (angle) and distance (radial) with reference to the centre of the goal line, a principal and common focus of both teams. As expected, the varying synchronies observed between the teams and ball for both angles and radial distances demonstrated game behaviors anchored on the competing game objectives of the attacking and defending teams (see Figure 6.5.).

The relative phase between the defending team and ball produced stronger in-phase attractions for angle measures than for radial distance. These results are explained by the defending team seeking to guard space by positioning itself with respect to the changing ball position and the goal being defended. By way of analogy, the defending players, and thus the defending team, may be thought of in general terms as patrol agents, being anchored to the goal centre on a "retractable leash" of some maximum length. This interpretation offers additional explanation for the earlier reported finding of weaker attractions with the defending team and ball in the longitudinal direction than the lateral direction. Since the attacking team are able to change the angle information of the ball with respect to the centre goal line more effectively by lateral displacements than by longitudinal displacements, it would seem reasonable to expect the defending team to be more responsive to ball displacements in that direction. This interpretation is reinforced further when considering that ball displacements in the longitudinal direction may generally be treated with varying degrees of attention by the defending players, depending in part on whether the ball is being displaced towards or away from goal. The main contribution of using polar coordinates was to undertake game behavior analyses while accounting for the key game objectives, namely that of attacking and defending a given goal.

In summary, individual and team coordinated behaviors are the result of information exchanges among dyads whose varied compositions on different levels may be considered as cooperative and/or competitive. Within this context, the results of this investigation have shown that ball kinematics is a key constraint that influences the dynamical behaviors of the players and teams, with general in-phase attractions being reported for the two teams, as well as for each team and ball. The attacking team demonstrated weaker in-phase coordination patterns with the ball than the defending team, a result interpreted as consistent with the attacking team trying to break synchrony with the defending team. Other than ball kinematics, the goal line was also shown as a key informational constraint that influences the coordination patterns, particularly for the defending team as demonstrated from considerations of angle and radial distances expressed with regard to the centre of goal. Thus, the defending team attempts to develop and maintain spatiotemporal coordination patterns with the attacking team, and with the ball, but, importantly, it does so within the context of considering kinematic information with respect to the goal line. Identifying and developing new variables for describing the coordination patterns that emerge in team sports as a result of ecological considerations and dynamical principles should aid future understanding of game behavior.

6.6.References

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6.7.Appendix

Table 6A1 - Relative phase post hoc results for: (a) the defending team, and (b) the attacking team, both with respect to the ball, using Cartesian coordinates.

	(a) defending team													(b) attacking team											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1	—			*	*	*	*						1	—					*	*	*				
2		—		*	*	*	*						2		—		*		*	*	*				
3			—		*	*	*						3			—				*					
4	*	*		—	*	*			*	*	*	*	4		*		—			*					
5	*	*	*	*	—	*		*	*	*	*	*	5					—							
6	*	*	*	*	*	—	*	*	*	*	*	*	6	*	*				—					*	*
7	*	*	*			*	—	*	*	*	*	*	7	*	*	*	*			—		*	*	*	*
8					*	*	*	—					8	*	*						—		*	*	*
9				*	*	*	*		—				9							*		—			
10				*	*	*	*			—			10							*	*		—		
11				*	*	*	*				—		11						*	*	*			—	
12				*	*	*	*					—	12						*	*	*				—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * $p < 0.001$.

Table 6A2- Relative phase post hoc results for the teams combined and ball for: (a) the lateral direction, and (b) the longitudinal direction.

	(a) lateral direction													(b) longitudinal direction											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
1	—				*	*	*	*					1	—					*	*	*				
2		—			*	*	*	*					2		—				*	*	*				
3			—		*	*	*						3			—			*	*					
4				—	*	*							4				—		*	*	*				
5	*	*	*	*	—				*	*	*	*	5					—							
6	*	*	*	*		—	*	*	*	*	*	*	6	*	*	*	*		—			*	*	*	*
7	*	*	*			*	—	*	*	*	*	*	7	*	*	*	*			—		*	*	*	*
8	*	*	*			*	*	—		*	*	*	8	*	*		*				—			*	*
9					*	*	*		—				9						*	*		—			
10					*	*	*	*		—			10						*	*			—		
11					*	*	*	*			—		11					*	*	*	*			—	
12					*	*	*	*				—	12					*	*	*	*				—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * $p < 0.001$.

Table 6A 3 - Relative phase post hoc results for the two teams combined, using Cartesian coordinates.

	1	2	3	4	5	6	7	8	9	10	11	12
1	—					*	*	*				
2		—				*	*	*	*			
3			—			*	*	*				
4				—		*	*					
5					—		*					
6	*	*	*	*		—					*	*
7	*	*	*	*	*		—		*	*	*	*
8	*	*	*					—	*	*	*	*
9		*					*	*	—			
10							*	*		—		
11						*	*	*			—	
12						*	*	*				—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * p < 0.001.

Table 6A 4 - Relative phase post hoc post hoc results for: (a) the defending team, and (b) the attacking team, both with respect to the ball, using polar coordinates.

	(a) defending team													(b) attacking team											
	1	2	3	4	5	6	7	8	9	10	11	12		1	2	3	4	5	6	7	8	9	10	11	12
—																									
1	—					*	*	*					1	—					*	*	*				
2		—				*	*	*					2		—				*	*	*				
3			—			*	*	*					3			—			*	*	*				
4				—		*	*	*					4				—			*					
5					—	*	*	*					5					—		*					
6	*	*	*	*	*	—	*			*	*	*	6	*	*	*			—					*	*
7	*	*	*	*	*	*	—	*	*	*	*	*	7	*	*	*	*	*		—			*	*	*
8	*	*	*	*	*			—	*	*	*	*	8	*	*	*					—		*	*	*
9							*	*	—			*	9									—			*
10						*	*	*		—			10							*	*		—		
11						*	*	*			—		11						*	*	*			—	
12						*	*	*	*			—	12						*	*	*	*			—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * p < 0.001.

Table 6A 5 - Relative phase post hoc results for the two teams combined, using Cartesian coordinates.

	1	2	3	4	5	6	7	8	9	10	11	12
1	—					*	*					
2		—				*	*					
3			—			*	*					
4				—			*					
5					—							
6	*	*	*			—				*	*	*
7	*	*	*	*			—	*	*	*	*	*
8							*	—				
9							*		—			
10						*	*			—		
11						*	*				—	
12						*	*					—

Note. 1 = -180º, 2 = -150º, 3 = -120º, 4 = -90º, 5 = -60º, 6 = -30º, 7 = 0º, 8 = 30º, 9 = 60º, 10 = 90º, 11 = 120º, and 12 = 150º. — = Diagonal cell. * $p < 0.001$.

7. General Discussion

The studies described in this thesis contributed to understanding of how individual players or teams adapt their behaviors to the conditions of the performance environment in order to perform successfully. Grounded on an ecological dynamics approach it is suggested that the fit between individuals and environment can be studied by identifying the informational variables that sustain emergent functional behaviors. Hence, the identification of environmental conditions which sustains functional patterns of interpersonal coordination helps to characterize the decision-making behaviors used to achieve a specific performance goal.

In this final chapter an overview of the results of all the studies presented in this thesis will be presented, and the major findings discussed. Based on the general discussion of the results, some important considerations for future research are also presented.

7.1.Overview

Chapter 2 highlighted that the experimental setup and the variables used to measure decision-making are paramount to capture expertise in decision making. By varying experimental task constraints, variables related to performance of actions (e.g., response accuracy) may result in different outcomes. Based on these results it can be affirmed that it is important to measure representative performance contexts that consistently allow differences in decision-making expressed by actions to be captured. Moreover, it was observed that variables such as movement accuracy and movement time have been neglected by some research programs in decision-making. In a research program, the perception-action coupling of analyzed individuals is a key issue for the study of decision-making. What is needed in research is the maintenance of the same ecological constraints of the performance environment in which sportive actions are produced grounded on the use of the specifying variables, i.e. representative designs (Araújo et al., 2007).

Chapters 3 and 4 showed how the behaviors of individuals were guided by the detection of affordances during competitive performance. In chapter 3, the results revealed how a decision to pass a ball to a teammate was regulated by the achievement of stable spatial constraints defined by the position of opponents in relation to the ball carrier. Moreover, it was also observed that, at the moment of pass initiation, the coupling between performers' distances was positive with high values. These results suggest that the strength of coupling between interpersonal distances sustains the local rules for perception and action allowing the emergence of a pass. In chapter 4, based on the same competitive futsal performance setting, we evaluated differences in the nature of spatial-temporal variables that allow the emergence of successful and unsuccessful passes. Results revealed that initial distances between ball carrier and opponents constrained successful interceptions. Successful interceptions also seemed to be influenced by the continuous regulation of the performer's movement velocity to the changing spatio-temporal constraints of the task. The variable time to ball interception, based on spatial-temporal relations between ball trajectory and opponents actions, was instrumental in shaping the emergent functional behaviors of performers. The adjustment of individual's velocity in relation to the time required to intercept the ball is paramount for a ball interception. It is worth noting that the capture of kinematic data and the identification of changes in the dynamics of individual's performance relative to the performance environment supported the view that passing decision-making processes are guided by the spatial-temporal relation between the performers and the ball.

Chapters 5 and 6 highlighted that the emergence of spatial-temporal patterns of coordination between players (chapter 5) and teams (chapter 6) during an actual competitive performance setting of futsal were constrained by the goals of the attacking and defending teams, the ball dynamics and the position of the goal. In chapter 5, results revealed that defenders demonstrated strong relations with the ball and with each other whereas an increased variability was observed for the attackers and ball, as well as between attackers themselves. These results demonstrated different coordination tendencies for the attacker-defender dyads, which were consistent with the different team performance goals. That is, the attacking team seeks to disrupt defensive team by increasing variability in their relations and the defending team tries to restrict space for the opposition by consistently stabilizing their relations with the ball and with each other. In chapter 6, results revealed stronger relations between the ball and the defending team than between the attacking team and the ball. The phase relations between the ball and the teams demonstrated complementary associations with each other. As an example, when the defending team presented a stable relation with the ball it decreased the stability of the relations with the attacking team. The opposite relation occurred when the defending team increased the stability of relations with the attacking team. Furthermore, the strongest relations were observed using angles to measure the associations between the defending team and the ball. Thus, the defending team continuously attempted to develop and maintain spatial-temporal coordination patterns with the attacking team, and with the ball, but importantly, it does so with respect to the spatial boundary created by the goal line location.

7.2.Information supports decision-making of players and teams during performance

The main focus of investigation in this thesis was to capture the emergent patterns of coordination tendencies that allow a better understanding of how information can support decisions and actions of individuals and teams during sports performance. Specific sub-phases of futsal game were used as task vehicles to study these phenomena, and the data seem elucidative: information constraints regulate functional patterns of coordination between individuals and teams on the basis of coupling tendencies. Particularly, spatial-temporal relations between players and teams in relation to ball dynamics seem to afford opportunities for action that players continuously explore in a goal-directed way.

An important issue to capture decision-making and action seems to be the type of experimental design employed. In the meta-analysis research we observed that the consistency of behaviors was stronger when the type of stimulus was specific to the performance environment and when actual sport actions were part of the experimental set-up. Apart from the relatively small number of studies observed for movement accuracy variables, data revealed the highest overall effect size for studies using sport actions in comparison with other dependent variables. Contrary to other dependent variables, goal directed behaviors measured with movement accuracy variables required participants to make perceptual judgments under specific performance environments, which allowed the emergence of unrestricted functional responses. Furthermore, consistency results in perceptual movement variables (eye movement measures) revealed differences in relation to a previous study (Mann et al., 2007) on perceptual movement behavior (i.e., in our results eye movement measures revealed inconsistency and in previous study revealed consistency). The differences between the two studies highlighted that perceptual behavior was also dependent on the type of goal proposed in the research task. Thus, the type of behaviors measured and the task goals proposed are also important issues to consider in research on decision-making.

The experimental designs proposed by this thesis followed this premise. In all of the experiments a specific sub-phase of competitive futsal games was used, in which performers attempted to achieve the main performance goal of the game. By highlighting distinct levels of relations in the game we isolated different behaviors for study, maintaining the specifying variables of the performance environment. With this methodology it was possible to understand perceptual-action coupling principles that guide behaviors of performers and teams at different scales of analysis (Gordon, 2007; McGarry et al., 2002).

The consideration that decision-making for action during performance is highly dependent on the perception of affordances provides a framework to understand the continuous control of action and the emergent patterns of coordination observed between performers. Affordances represent the constant fit between individual constraints and invariant properties of the environment that allow achieving an intended goal within converging possibilities for action (Araújo et al., 2006; Turvey & Shaw, 1999). Chapters three and four provided some evidence that perception of possibilities for action during sport performance is based on the adaptation of performers to spatial-temporal informational constraints of the game. In particular, changes in interpersonal distances and variations in the relative velocity of performers constituted important sources of information that guided their perceptions and actions. These spatial-temporal adaptations during performance were based on the capabilities of each player, but were also based on the perception of opportunities of others to act (Richardson et al., 2007). As observed in chapter three, to perform successful passes, instants before of the pass initiation performers increased and stabilized the coupling between their interpersonal distance values in order to create functional spatial-temporal patterns of coordination. One important aspect highlighted in both chapters is the stability in environment at the moment of pass initiation. Performers seem to perform a pass to a teammate under specific conditions related with interpersonal distances to opponents. Moreover, the capacity of opponents to intercept the pass seems to be influenced by the interpersonal distances between the ball carrier and opponents at the moment of pass initiation. However, it was also observed that it was not just the distance between performers that constrained their decision to pass the ball or to intercept it, but it was also the capacity to change individual velocity at the moment of pass initiation. Our results revealed that the ball carrier and the opponents changed velocity according to initial conditions in each trial, in order to adapt their behaviors to the spatial-temporal constraints of performance. In line with these results the information that sustain affordances can be captured during performance. For that, it is needed to consider interpersonal relations, as well as each performer's capacity to change individual velocity over time. The variable time to ball interception (TBI), proposed in the fourth chapter, seems to describe the spatial-temporal informational constraints that guide decision-making behaviors. Levels of variability in TBI at the beginning of the trials, for passes intercepted, decreased and achieved stability in negative values only close to the moment of pass interception. These results revealed that the capacity to intercept the pass was not prescribed when the ball carrier performed a pass. It emerged from the continuous adaptations of performers to the conditions of the environment in a prospective way based on changes on spatial-temporal information of their position in relation to opponents behavior and ball trajectory. Hence, future research needs to capture behavior patterns that sustain the relation between individuals and the environment in different task goals, such as to kick to the goal, to defend an opponent, to intercept a ball, to feint an opponent and so on.

In a more general view, behavior in the game and in its sub-phases should be viewed as a self-organizing process whose patterned features emerge from the playing interactions operating under various constraints (Davids et al., 2008). Thus, with the varying information exchanges among playing dyads and teams, a high number of possibilities for action emerge comprising the underlying basis for game dynamics (McGarry et al., 2002). With this idea in mind, team sports such as futsal may be investigated at different levels, from individual player interactions to collective team interactions (McGarry et al., 2002). Chapters five and six evaluated space-time movement patterns between dyads and teams, respectively. The ball dynamics and goal position were additional informational constraints (Davids et al., 2008; McGarry, 2009) that were considered for advancing understanding of game behavior.

Results of dyadic system analysis were quite similar to results of team analyses but displayed highest variability in interpersonal relations and consequently weaker phase attractions. In general, it was observed a strong relationship between a defending team, ball dynamics and the position of the goal. The relationship between attacker-defender dyads or attacker-ball pairs were weaker and presented more variability in the type of relations assessed.

Hence, the phase relations between dyads and teams demonstrated different results for the attacking and defending teams because of the opposite game objectives.

Individual and team coordinated behaviors can be considered as a result of information exchanges among dyads and teams in which ball kinematics and goal position are key informational constraints that influence the emergent coordination patterns. Thus, the defending team attempts to develop and maintain spatial-temporal coordination patterns with the attacking team, and with the ball, but importantly, it does so within the context of considering kinematic information with respect to the goal line. Alternatively, attacking teams demonstrated high variability in the coordination patterns with the ball and defending teams, as well as between the dyads of attackers, a result interpreted as an attempt to break synchrony with the defending team to gain space and time to shoot at goal. Coordination dynamics between the defending team, and attacking team in relation to ball dynamics and goal position emerged from the competition and cooperation of functional spatial-temporal information available, and the self-organized tendencies of the system.

It is worth noting that during this research programme, a five-versus-four plus goalkeeper (5-v-4+GK) sub-phase of futsal was used as the experimental task vehicle. This is a common game strategy which allows the team numerical outfield player advantage with the express purpose of increasing goal scoring opportunities. These changes on game's constraints (5x5 or 5x4+GK) allowed the emergence of different coordination patterns for game behaviors produced under typical game conditions. That is, when both teams contained four outfield players plus goalkeeper, as compared to the less balanced 5-vs-4+GK sub-phase considered in this report. These changes in the number of outfield players were also important informational constraints that need to be accounted to understand its influence on game dynamics. Further research is required on these specific issues.

7.3.Conclusions

We observed that performers' behaviors during competition were guided by the continuous flow of informational constraints based on spatial-temporal information. The continuous changes in velocity of each performer reflected an attempt to adapt their behaviors to environmental constraints, especially the ball dynamics, the position of the goal, and also the time to ball interception in order to perform or intercept a pass during the game. The results reinforced that spatial-temporal relations between players and ball, between players of the same team, and between players of opposing teams, subscribing to the theoretical principles of dynamical systems. Thus, in agreement with other research on team sports (Araújo et al., 2006; Araújo et al., 2010; Correia et al., In Press; Passos et al., 2009) we highlighted that tactical behaviors in futsal should be seen at the level of the interactions between the individual and the environment.

It was observed that the decision-making process in team games is dependent on the exploration of the environment, promoting the achievement of functional conditions of performance. Based on an ecological dynamics approach these studies have raised new questions related to the variables that guide performers' behaviors, the emergence of different patterns of coordination for different sub-phases of game, or new variables for describing coordination patterns that emerge during performance with reference to the ball dynamics or to the goal.

7.4.Future research

During this research program some questions were raised that might constitute interesting topics for future research. In chapter three and four a description of the conditions that underlie pass performance and pass interception was developed. However, it is also needed to identify in controlled environments the conditions that could afford passing performance, for individuals with different levels of expertise. Improving this information it is possible to better define some critical values of environmental conditions that afford a certain type of action. Using virtual reality to control the conditions of environment and to understand the magnitude of the adaptation of each participant to the manipulation of each variable (e.g., distance between ball carrier and defender, distance between defenders, angle between both attackers and defenders or the velocity of approach of defenders to ball carrier) may be an option to consider. Using this technology, it may be possible to maintain perception-action coupling in a more controlled way, as proposed in other studies of team sports (Craig, Berton, Rao, Fernandez, & Bootsma, 2006; Watson et al., In press). Another possibility for further research is to test the effects of information manipulation on the movement adaptations of participants. For instance by highlighting some information and suppressing other sources during similar tasks. In order to capture the different visual search strategies and the resultant action adaptations, representative tasks of passes with variation of the distances and velocities of defender players could be also considered. For that, an eye-tracking system is required in order to compare the individual patterns of search information with the individual patterns of performance (Dicks et al., 2010).

Based on data from chapters five and six, in order to test the effects of numerical outfield player advantage on dyadic and team patterns of coordination, a comparison between a 5-v-5 and a 5-v-4+GK needs to be performed. In addition, identifying and developing more robust variables for describing the coordination patterns of game with reference to ball dynamics and position of the goal or other references in the field is required. Further attention is needed on the kinematic relations between players and the ball in longer trials. We consider that it will allow a better description of game dynamics with a clear identification of critical fluctuations that afford transitions on game patterns of coordination. Finally, using a dyadic sub-system and a team level analysis of game dynamics for performance at different levels of expertise can help to develop a reliable system for evaluation of the level of expertise of each performer or team. A multi-level approach that capture the contribution of each player in a given time to the behavior of the team, or the identification of the critical fluctuations in both levels that allow the emergence of a goal, could help to better understand the physical and informational laws that sustain game dynamics.

8. References

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