Interpersonal coordination and ball dynamics in futsal (indoor football)

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A B S T R A C T

Here, we report an investigation of the patterned movement behavior 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, were 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 for complex systems, we view 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.

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1. 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 discards much of the 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, Araújo, Correia, & Esteves, 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 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, Button, & Bennett, 2008). Then, the collective behaviors produced by team sports should not be considered the aggregate result of individual playing behaviors (Araújo, Davids, & Hristovski, 2006), but, instead, a synergistic result of cooperation and competition among players of the same team and between players on opposing teams, respectively (Gréhaigne, Bouthier, & David, 1997; Lames, 2006; McGarry, Anderson, Wallace, Hughes, & Franks, 2002). Thus, the dynamical behavioral structure of team sports may be investigated at different levels, from individual player interactions (e.g., Bourbousson, Sève, & McGarry, 2010a) to collective team interactions (e.g., Bourbousson, Sève, & McGarry, 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; Schmidt, O’Brien, & Sysko, 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 a 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, Davids, Araújo, & Button, 2006), and rugby (Passos et al., 2009) have employed 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 (0°) and anti-phase (180°), where both agents are at the same or opposite places in their particular cycles. Put differently, the in-phase and anti-phase relations correspond respectively to symmetrical and anti-symmetrical periodic relations between agents (Kelso & Engström, 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 constitutes 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 thus be considered, 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 × 20 m 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 zone-based 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).

2. Method

2.1. 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.

2.2. 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.

2.3. 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, thus 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 Fig. 1).

2.4. 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 center, 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 Fig. 1).

The relative phasing of the time series data were obtained using the 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 $12 \times 2$ mixed model ANOVAs, with repeated measures on the relative phase bins and the second factor being direction (lateral-longitudinal) or team (attack-defence), 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).

![Fig. 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).](image-url)
2.5. 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 m (3.645%), 0.185 m (1.749%) and 0.235 m (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 ($R = .993$).

3. Results

3.1. 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.

3.2. Coordination dynamics between the defenders and ball

Fig. 2 (upper panels) presents 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 $-60^\circ$ through $0^\circ$ phase relations to yield distinct differences from the other coordination patterns (see Table A1a).

Unsurprisingly, the significant post hoc differences for the $-60^\circ$, $-30^\circ$ and $0^\circ$ phase relations are observed in higher frequencies in the histogram data, with visual inspection indicating a pronounced $-30^\circ$ 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.

3.3. Coordination dynamics between the attackers and ball

Similarly, Fig. 2 (lower panels) reports 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 $-60^\circ$ through $60^\circ$ phase values and those of $-150^\circ$ through $-210^\circ$ (see Table A1b). (Note. $150^\circ$ and $-210^\circ$ denote the same phase relation because of the circular statistics used to express relative phase.) Visual inspection of the relative phase histogram data further demonstrated weak attractions 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 A2a) and longitudinal (Table A2b) directions determined significant differences between the phase ranges $-90^\circ$ through $30^\circ$ (for lateral) and $-60^\circ$ through $30^\circ$ (for longitudinal) as compared with the $-120^\circ$ through $-300^\circ$ values (i.e., $-180^\circ$, $-150^\circ$, $-120^\circ$, $-90^\circ$, $60^\circ$, $90^\circ$, $120^\circ$ and $150^\circ$).

3.4. Intra-team coordination – defending dyads

The relative phase histogram for the defending dyads revealed strong in-phase attraction in both directions (upper panels, Fig. 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 $-60^\circ$ through $30^\circ$ and $-180^\circ$ through $300^\circ$ phase ranges (Table A3a).

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 $-30^\circ$ 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 Fig. 1 for general reference regarding the playing positions of the defenders, and the attackers who follow next.
3.5. 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, Fig. 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 A3b).

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 $/C0^/C176_60^/C176$ through $30^/C176$ and the $/C0^/C176_180^/C176$ through $300^/C176$ phase ranges (Table A4a). Fewer differences were observed for the longitudinal direction, with significant findings between the $-60^\circ$ through $30^\circ$ phase range and remaining phase values (Table A4b).

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.

Fig. 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.
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.

3.6. 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 (Fig. 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 \(-60^\circ\) through \(0^\circ\) and \(-90^\circ\) through \(-300^\circ\) (Table A5).

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.).

4. 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 on behavior, 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).

4.1. 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 zone-based 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.

4.2. Coordination dynamics between player-ball pairs

Strong \(-30^\circ\) phase attractions between defenders and ball were reported for both lateral and longitudinal directions, particularly the former (Fig. 2, upper panels). Similar phase attractions in the lateral \((-30^\circ)\) and longitudinal \(0^\circ\) directions were reported for the attackers too, albeit to lesser extents indicating weaker phase couplings for these data (Fig. 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 kinematic 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).

4.3. 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, Glazier, Araújo, & Bartlett, 2003), shared objectives that might be considered as additional social constraints that help shape game behavior (Marsh, Richardson, Baron, & Schmidt, 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).

4.4. 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 defence 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).

4.5. 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 is 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.

4.6. 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.

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Table A1

Post hoc results for (a) the defenders and ball and (b) the attackers and ball.

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<th>(a) Defender-ball</th>
<th>(b) Attacker-ball</th>
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<tr>
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<tr>
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<tr>
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Note. 1 = $-180^\circ$, 2 = $-150^\circ$, 3 = $-120^\circ$, 4 = $-90^\circ$, 5 = $-60^\circ$, 6 = $-30^\circ$, 7 = $0^\circ$, 8 = $30^\circ$, 9 = $60^\circ$, 10 = $90^\circ$, 11 = $120^\circ$, and 12 = $150^\circ$. — = Diagonal cell. *$p < .001$.

Table A2

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

<table>
<thead>
<tr>
<th>(a) lateral direction</th>
<th>(b) longitudinal direction</th>
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Note. 1 = $-180^\circ$, 2 = $-150^\circ$, 3 = $-120^\circ$, 4 = $-90^\circ$, 5 = $-60^\circ$, 6 = $-30^\circ$, 7 = $0^\circ$, 8 = $30^\circ$, 9 = $60^\circ$, 10 = $90^\circ$, 11 = $120^\circ$, and 12 = $150^\circ$. — = Diagonal cell. *$p < .001$.

Table A3

Post hoc results for (a) defending dyads and (b) attacking dyads.

<table>
<thead>
<tr>
<th>(a) defending dyads</th>
<th>(b) attacking dyads</th>
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</thead>
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</table>

Note. 1 = $-180^\circ$, 2 = $-150^\circ$, 3 = $-120^\circ$, 4 = $-90^\circ$, 5 = $-60^\circ$, 6 = $-30^\circ$, 7 = $0^\circ$, 8 = $30^\circ$, 9 = $60^\circ$, 10 = $90^\circ$, 11 = $120^\circ$, and 12 = $150^\circ$. — = Diagonal cell. *$p < .001$.
Appendix A

See Tables A1-A5.

References


