5
SPORT COMPETITION AS A DYNAMICAL SELF-ORGANIZING SYSTEM

Coupled oscillator dynamics of players and teams underscores game rhythm behaviours of different sports

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Summary
This article traces development of research on sports behaviours in sports contests as complex self-organizing systems using principles of coupled oscillator dynamics. In short, relative phase analysis of kinematic data of players and teams are consistent with the idea that the collective behaviours that characterize different sports contests are the result of information-based interactions among coupled dyads. That different sports on different levels of analysis may be subsumed under a common description using coupled oscillators presents good reason for continued research in this regard for advancing understanding of sports behaviours. For a review of research investigations on sports behaviours as complex self-organizing systems not predicated on coupled oscillator dynamics, the reader is directed to other chapters of this handbook as appropriate.

Introduction
Visual inspection of sports performances points towards structured patterned behaviours for sports contests. Put simply, however, the behavioural patterns observed from visual perception have not been well demonstrated in data that supposedly describe them (McGarry, 2004). Sports performance data often get recorded using reductionist methods (e.g. the auditing of ‘on-the-ball’ sports behaviours in discrete sequential fashion of the type ‘who-what-where-when’) with the general intent of identifying meaningful associations between sports behaviours and sports outcomes (McGarry, 2009). This approach has yielded limited progress, however, and the implications for advancing understanding of sports performance and informing future sports practice should not be overlooked.
Dynamical self-organizing systems

The idea of patterned behaviours in sports contests is described in the concept of signature behaviours. McGarry and Franks (1996) analysed shot selections and outcomes (winners and errors) of squash players for signature behaviours in view of predicting future performances from past observations using probability-based (Markov-chain) analysis. For the most part, the results demonstrated changing probabilities when players competed against different opponents, thus challenging the preconceived notion of signature behaviours, at least as measured using probability (percentage) behaviours, and questioning moreover the general accepted sports practice of applying information obtained from past observations in preparation of future performances (cf. scouting).

Should there be merit to scouting practice as supposed, then the ‘who-what-where-when’ system description used might be questioned instead. To the point, that sports behaviour data obtained for performance analysis might not be as patterned as otherwise thought opens the prospect of insufficient system description (McGarry and Franks, 1996). Perceptual experiences tend towards this viewpoint, which, if accepted, obliges a rethinking of data required for meaningful description of sports contests. On this reasoning, previous approaches investigating game behaviours using the reductionist method for providing system description were reconsidered and new thinking introduced considering sports games under the rubric of complex dynamical systems (McGarry et al., 1996; Gréhaigne et al., 1997).

Behavioural perturbations

In a keynote address to the First World Congress of Science and Racket Sports (1993), the insightful analogy of a dance couple was used to describe game behaviour produced in a badminton rally (Downey, 1993). This analogy suggests the badminton couple (dyad) as seeking to maintain behavioural synchrony in rallies while simultaneously looking for individual opportunities within rallies to disrupt synchrony at opportune times for advantage gain. (This same analogy applies equally well to combat sports such as fencing, boxing and other martial arts.) This observation prompted additional consideration, leading to the subsequent development and introduction by McGarry and Franks (1996) of ‘perturbations’ for sports contests, with illustrative examples offered from squash, soccer and rugby football, underscoring the generality of this description for sports contests. As noted in McGarry and Franks (1996), if the notion of perturbations in sports contests is accepted, then these behaviours would be considered key descriptors of sports performance, indicating that not all behaviours should be considered of equal importance (cf. probability analysis). Again, this consideration necessitated a rethinking of previous reductionist approaches to investigating sports behaviours, leading, ultimately, to a proposed new description for sports contests from that produced hitherto (McGarry et al., 2002).

The concept of perturbations for sports contests is important in that perturbations mark the boundaries of behavioural change, thereby serving as signposts for identifying different coordination behaviours at different instants. Visual observation presents a good means for detecting perturbation behaviours in sports performance on two counts. First, introduction of the dance-couple analogy for badminton dyad behaviours was itself observation based and, second, the method of using visual observation in other social contexts was successful when investigating behavioural synchrony in mother–infant dyads (Bernieri et al., 1988). For these reasons, McGarry et al. (1996) used human observers as the measurement instrument when examining sports (squash) contest behaviours for evidence of perturbations. Both experts and non-experts were tasked separately with identifying behavioural perturbations, if any, from video records comprising 60 squash rallies selected at random from highest-level tournament.
competition. More specifically, the observers were tasked with identifying those instants (shots) in any given rally perceived as changing (perturbing) squash dyad behaviours between periods of ‘stability’ and ‘instability’. In general, good agreement between independent observers was reported, giving strong validation for the concept of behavioural perturbations in sports (squash) contests. Furthermore, in some rallies, multiple perturbations were identified, indicating repeat transitions between bouts of stable and unstable squash dyad behaviours. Additional evidence regarding the presence of these behavioural perturbations together with kinematic data interpreted in context of dynamical self-organizing systems was reported in McGarry et al. (1999).

Behavioural perturbations in sports contests have also been reported from visual observations for football (Hughes et al., 1998) and tennis (Jörg and Lames, 2009), offering additional support to the generality of this system description for different sports as proposed by McGarry and Franks (1996).

**Complex systems**

The basic premise of complex systems is that function (behaviour) results from self-organizing interactions among the system parts by virtue of information exchanges. System function is considered self-organizing in that regularity of behaviour is not preordained by means of instruction by some outside agency but instead produced from within. The collective behaviours observed for schools of fish, flocks of birds, societies of ants and African termite colonies offer some examples of complex systems. The general thesis presented here is that the collective behaviours of players in sports competition may likewise be explained by complex systems principles.

Take the nesting behaviours of African termites as an example. According to Kugler and Turvey (1987), these insects build nests by collective self-organizing behaviours as follows. Individual termites initially acquire nesting material that they later drop on a random basis. Together with the nesting material, however, the termites leave pheromone (scent) deposits, which increase the likelihood of attracting additional drops of nesting material from other termites. Further drops of nesting material are likewise accompanied by additional deposits of pheromones, with increasing pheromone gradients (information fields) increasing the likelihood of yet more nesting material, and so on. In this way, a number of pillars of nesting material are built in close proximity to each other, which subsequently connect by arches to form the base for the next layer, and the process repeats. Thus, individual structures are constructed by self-organizing interactions among termites according to physical principles (information exchanges) that govern system behaviours without design specification. This common description of nesting behaviours produces unique results, with buildings that are nonetheless recognizable (patterned), and, moreover, affords an understanding of system behaviour that otherwise may well be obscured by reductionist methods. The possibility is that sports performances may benefit from similar considerations, although this analogy of African termites for sports contests, introduced by McGarry and Franks (1996) and McGarry et al. (1996), should not be taken as literal. Sports players should not be considered as depositing pheromones at various positions on the fields of play, so developing increasing information fields (or gradients) and increasing likelihoods of additional behavioural actions at certain locations. Not yet anyway.

**Coupled pendulums**

Pendulums exhibit cyclical behaviours as they pass periodically by reason of gravity through some nadir on transit between two opposing zeniths. Regarding coordination, Huygens reported ‘sympathy’ in the behaviours of two pendulums when swung separately but suspended
Dynamical self-organizing systems

from a common frame – for additional context on the importance of this finding in respect to the ‘coordination problem’ for producing movement behaviours, see Meijer (2001). This result demonstrates self-organized behaviour by means of common information exchanges between pendulums – that is, unified behaviour is produced courtesy of mutual influences of each pendulum on the other. Once more, then, the answer to the ‘coordination problem’ is found from within the system and not from outside as a result of intelligent design by some external agent (Turvey, 1990). The specific thesis presented here is that the coordinated behaviours observed in sports contests are likewise attributed to mutual influences among players, a non-prescribed emerging result of ongoing information exchanges between players, rather than an intended consequence of outside intelligence.

Coordination

In time, the self-organization of coupled pendulums settles into one of two possible coordination patterns, in-phase and anti-phase. In-phase represents the same positions of the two pendulums in their respective cycles at the same time, and anti-phase represents the positions of both pendulums with one displaced a half cycle from the other at any instant. Thus, the two pendulums will reach the same zeniths at the same times for in-phase and opposing zeniths at the same times for anti-phase, while passing through their nadir at the same time for both phase relations. For completeness, other values of relative phase between in-phase and anti-phase remain possible for the two pendulums too, in the formal sense at least, if not sustained in practice.

These observations on coupled pendulums are considered important for coordinated actions of animals and humans. For example, a series of linked pendulums offers a sound basis for modelling animal gait (see Kugler and Turvey, 1987, for accounts of quadrupedal gaits for various animals). Also, the same accounting of coordination on the basis of coupled pendulums applies at different levels of analysis. Take quadruped gait for consideration – at one level, the couplings of pendulums (e.g. joints: ankle, knee and shoulder/hip) produces coordination within a limb (i.e. leg) and at another level the couplings of pendulums (e.g. legs) produces various coordination patterns recognized as different quadruped gaits (i.e. walk, trot or canter, and gallop). That the same principles of coupled pendulums (oscillators) explain the varied coordination behaviours of quadrupeds at different levels of consideration makes a compelling argument for complex dynamical self-organizing systems as an underlying basis for their coordination.

To demonstrate the proposed importance of this approach for explaining coordinated behaviours of sports contests, we turn first to some well-known ‘finger wagging’ experiments by Kelso and colleagues (e.g. Kelso et al., 1981; Kelso, 1984; Haken et al., 1985). Here, changing coordination stabilities of anti-phase and in-phase were reported, as well as phase transitions from anti-phase to in-phase as a result of anti-phase destabilization when the cycling frequencies of two index fingers oscillating (flexing–extending) in the transverse plane were increased towards and beyond ‘critical’ values. In introducing dynamical systems theory for human rhythmic coordination, Haken et al. (1985) developed a formal description for these dynamic coordination results using two coupled oscillators (pendulums). This description was subsequently extended to encompass other rhythmic movement behaviours – for example, the coordination of multiple joints (Kelso et al., 1991) as well as multiple limbs (Schöner et al., 1990; Kelso and Jeka, 1992). This same accounting was later applied successfully to the coordination behaviours produced by two persons in a leg-swinging coordination task (Schmidt et al., 1990). Thus, dynamical principles of self-organizing systems for coordinated rhythmic behaviours apply equally well both within and between persons (see Schmidt et al., 2011, for further details on aspects of social motor coordination dynamics).
Sports contests

In this section, the coordinated behaviours produced in sports contests are the proposed result of self-organizing interactions among coupled oscillators – that is, players and/or teams (McGarry et al., 2002). From the dance-couple analogy, the suggestion of coupled oscillators for explaining sports contest behaviours emanated from developing considerations by McGarry and Franks regarding squash contest behaviours in the context of self-organizing coordination dynamics (see McGarry and Franks, 1996; McGarry et al., 1996, 1999). This reasoning was advanced by McGarry et al. (2002) on the same principles to encompass the different and varied game rhythms that characterize many different sports, from the to-and-fro behaviours of individual (1 vs 1) sports like squash, tennis and badminton to the ebb-and-flow behaviours of team (many vs many) sports such as basketball, soccer and hockey. In the following sections, research investigations that have examined various sports as self-organizing on the basis of dynamical systems principles, and specifically on the basis of coupled oscillator dynamics, are reported.

Individual sports: squash, tennis and badminton

To win points and games in squash contests, both players look to gain control of the space–time dynamics of their interactions by seeking ownership of the T-position located approximately centre court. In pursuit of this game objective, both players manoeuvre the other from the T by means of shot selections, while at the same time themselves moving towards the T to await the next shot in the rally sequence. Since players trade shots in turn within squash rallies, as one player leaves the T to make the next shot and returns to the T after doing so, the other player exhibits similar behaviour in alternating sequence. Thus, both players demonstrate oscillating movement trajectories to and from the T in anti-phase sequence as shots are traded. As before, the requirement for information exchange among coupled oscillators for producing self-organizing behaviours is present in the squash dyad, with visual information, playing strategies, habitual behaviours and the like offering possibilities for information-based couplings. These considerations led McGarry et al. (1999) to investigate the coordinated behaviours of squash dyads as a self-organizing dynamical system.

Reporting on the presence of behavioural perturbations in squash rallies, McGarry et al. (1999) also analysed the changing radial distances from the T of both squash players on four separate squash rallies. Visual inspection of the kinematic data demonstrated anti-phase coordination of the squash dyads, as expected on the reasoning described above, with short-lasting fluctuations from anti-phase observed on occasion. No correspondences between the behavioural perturbations identified by independent observers and these intermittent phase disturbances from anti-phase could be established however and further research on understanding the information basis for identifying behavioural perturbations in sports contests using human perception is required.

Following important research in tennis as a dynamical system reported by Palut and Zanone (2005), McGarry and Walter (2012) re-examined the movement behaviours of squash dyads using formal analytic calculations of relative phase. The kinematic variables subjected to relative phase analysis were displacements from the T and their rates of change (velocities) for each of the lateral (side-to-side), longitudinal (front-to-back) and radial directions. The six combinations for the reporting of relative phase produced understandably varying results, with bi-modal phase attractions observed in both lateral and longitudinal directions for both displacement and velocity metrics, albeit with different phase attractions for the different kinematic metrics used. In contrast, single anti-phase attraction in the radial direction was reported for both displace-

T. McGarry
ment and velocity. Part of these phase results using displacement data reported in McGarry and Walter (2012) were also reported in McGarry (2006).

As with the findings reported by Palut and Zanone (2005) from the lateral velocities of tennis players trading baseline shots, bi-modal phase attractions in the lateral directions were observed for the squash dyads. Also, as with the results of Palut and Zanone (2005), transitions between in-phase and anti-phase coordination was attributed to the squash players switching shot types between straight (line) and cross-court shots. Specifically, line shots produced anti-phase and cross-court shots in-phase coordination as the players moved in the opposite and same directions, respectively. Similarly, bi-modal phase attractions for the squash dyads were reported for the longitudinal directions on the same reasoning – that being the shot exchange combinations between short and long shots being responsible for the transitions between in-phase and anti-phase. These results demonstrate that additional information is obtained from analysing movement kinematics in both lateral and longitudinal directions instead of using a single direction (radial), which, necessarily, results in some loss of information. Regardless, the various combinations of kinematic metrics and directions produced results consistent with dynamical system behaviours, be it single anti-phase behaviour or bi-modal phasing with intermittent transitions, depending on the measures used.

As stated already, information-based coupling is key in accounting for squash dyad behaviours as self-organizing. This requirement for information exchange was assessed by McGarry and Walter (2007) by analysing relative phase for different combinations of squash dyads. Take the squash dyads of AB and CD, for instance, where A, B, C and D represent different players observed in two separate contests (i.e. AB for one contest, CD for the other). If the reported phase attractions for AB and CD result from information-based coupling, as hypothesized, then AB and CD would be predicted to demonstrate stronger phase attractions than the other synthetic combinations of AC, AD, BC and BD, whereby any phase attractions would be attributed to chance associations by way of two separate oscillators (squash players) operating independent of the other. This prediction was upheld in results reported by McGarry and Walter (2007), producing good evidence for the reasoned argument that the coupling behaviours of squash dyads are indeed information based, as expected given the common principal means for information exchange between the two players – the ball.

From individual sports to team sports

The suggestion that space–time kinematics of the squash dyad subscribes to dynamical self-organizing principles was expanded to include many different types of sports contest (McGarry et al., 2002). First, these authors suggested a common description for the racket sports of squash, tennis (including table-tennis) and badminton, as the players in these sports all demonstrate oscillating movements. For squash, as noted, the locus of oscillation for both players (the T) is shared, whereas in tennis and badminton each player oscillates about his (her) own locus. In squash, a player looks to control space–time dynamics by moving his (her) opponent around the shared playing surface with shot selections. In tennis and badminton, a player does likewise but this time only in respect to the half-court of the opponent. The different game characteristics determine that the locus of oscillation for the tennis player is the centre of his (her) own baseline, or thereabouts, whereas for the badminton player it is the centre of his (her) defending half-court, or thereabouts. These differences notwithstanding, the racket sports conform to a common system description, at least in principle – that being a self-organizing system predicated on information-based coupled oscillator dynamics.

The same consideration of coupled oscillator dynamics for the racket sports extends to doubles play. For distinction, we used the term intra-couplings to reference the interactions of
two players comprising a playing double, and inter-couplings in reference to the interactions between two players from opposing doubles, as well as between opposing doubles themselves. Once again, the thesis is that individual players demonstrate oscillating movements about some locus with information-based interactions among playing dyads providing the basis for self-organized coordinated behaviours. Note that the same description applies for the playing doubles – that being a playing dyad comprising the playing doubles. Thus, the playing doubles likewise demonstrate oscillating movements about some locus with information exchanges between the two doubles again producing self-organizing outcomes.

At this juncture, the concept of changing locus of oscillations should be introduced. In singles tennis, a player will tend to oscillate about the mid-baseline, as suggested previously. However, sometimes a player will follow-up an attacking shot from the baseline by approaching the net. Alternatively, a player may be drawn towards the vicinity of the net in response to a drop shot from the opponent. Both examples might or might not constitute behavioural perturbations depending on whether or not the tennis rally is destabilized. Both examples constitute a ‘transition’ however if, as oftentimes happens, the approaching player thereafter occupies the new mid-position a short distance in front of the net for the remainder of the rally, or until forced back to the baseline some time later in reply, say, to a lob shot from the opponent. (Here, the term ‘transition’ refers to a change in locus of oscillation and not necessarily a change in relative phasing in the dyad.) Thus, two possible loci of oscillations for the single tennis player exist, with occasional transitions between them depending on game context (see Figure 5.1). Similarly, in badminton doubles play, a double will generally adopt a lateral (side-to-side) or longitudinal (front-to-back) playing formation within a given instant of a given rally, with intermittent transitions sometimes observed between these two formations depending on game circumstances (see Figure 5.2).

Similar considerations of coupled oscillator dynamics from singles play to doubles play were extended to include other team sports, such as basketball, hockey and soccer. First, however, we should note the different natures of individual sports like squash, tennis and badminton (includ-
Dynamical self-organizing systems

ing doubles play), where possession is traded in equal fashion, from these types of team sports, where possession is exchanged in unequal measure. Nonetheless, some common underpinnings for game behaviours are suggested in the structured to-and-fro of individual sports and the less structured, but structured nonetheless, ebb-and-flow rhythms of team sports that characterize these different sports. As before, these proposed underpinnings are attributed to coupled oscillator dynamics, with the collective game behaviours of team sports now considered the result of couplings among many dyads on many levels, from player dyads through partial-team dyads (comprising two or more players per team) to the team dyad. The next section describes research on team sports as dynamical systems.

**Team sports: basketball, football and futsal**

The notion that team sport behaviours subscribe to dynamical self-organizing principles at different levels of analysis, a result of coupled interactions of dyads from players to teams, was investigated in the analysis of basketball game behaviours by Bourbousson and colleagues. These authors recorded the movement kinematics of all players and consequently reported relative phase analysis for all combinations of playing dyads in both lateral (side-to-side) and longitudinal (basket-to-basket) directions (Bourbousson et al., 2010a). The results demonstrated in-phase attractions of playing dyads in both directions with stronger associations observed in the longitudinal direction. In-phase attractions within playing dyads were furthermore influenced by their make-up, with dyads containing opposing players matched on playing position reporting the strongest phase attractions, a finding attributed to the individual defensive marking strategies used by both teams. Also, anti-phase coordination behaviour in the lateral direction was reported for playing dyads comprising the wing players from the same teams, an indication of tactical game behaviour with both players working in tandem to decrease width when defending and to increase width when attacking.

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**Figure 5.2** Representation of four loci of oscillations (1 through 4) for two badminton doubles players (C and D) and a transition between them. Badminton doubles occupy lateral formation (left panel). One badminton double (C) occupies a lateral formation and the other double (D) a longitudinal formation (right panel). The doubles may transit between lateral and longitudinal formations and hence loci of oscillations depending on game context.
Individual player kinematic data were combined to obtain geometric mean coordinates for investigating behavioural interactions of the teams (Bourbousson et al., 2010b). These data were subjected to investigation using relative phase metrics with similar results of in-phase attractions between teams in both directions, as expected. In-phase attractions were again stronger in the longitudinal direction than the lateral direction, and stronger also between teams than between players. This finding is consistent with statistical considerations, with the aggregating (or averaging) of data serving, in effect, to reduce variability in the time series data. Similar results were reported by Lames et al. (2010) in their analysis of football game behaviour by means of relative phase. Kinematic data of all players obtained from video records of the 2006 FIFA World Championship final between France and Italy were recorded and relative phase obtained from the centroid data (geometric mean) of both teams. Strong in-phase attractions were reported for both directions, although, unlike the basketball results, marginal stronger attractions were reported in the lateral (sideways) direction as opposed to the longitudinal (forward–backward) direction. This finding may well reflect the behavioural characteristics of these different sports, with more direct play in the longitudinal direction attributed to basketball game behaviour and more probing of opponent defensive structure in the lateral direction in football. This said, the results indicated remarkably strong in-phase attractions between the two teams in both directions, and relative phase investigation of playing interactions between partial-team dyads, specifically the midfield lines of both teams identified as comprising four players per team, as well as between a couple of select attacker–defender playing dyads from players of opposing teams, indicated that these findings extended throughout all levels of analysis.

Frencken et al. (2011) also examined football playing behaviours at the team level, this time from small-sided (5 vs 5) game practice (for 11 vs 11 data, see Frencken et al., 2008). Again, these authors investigated interacting behaviours between teams using centroid data as well as using measures of surface area. The distance between team centroids was interpreted as an indication of game ‘pressure’, with shorter distances taken as representing higher pressure applied by one or both teams. The surface area bounded by the team configuration perimeter was used to indicate player (or team) dispersion, with higher values indicating greater distribution of players in one or both directions. These authors did not undertake relative phase calculations. However, visual inspection of data nonetheless demonstrated strong in-phase attraction between teams for both centroid measures whereas the relation between surface area measures was less clear.

Research into team sports as dynamical self-organizing systems was extended by Travassos and colleagues by including ball kinematics in their investigation of futsal game behaviour (Travassos et al., 2011, in press). Futsal is a FIFA-regulated football game comprising two teams of five players (four outfield players plus goalkeeper) and is played indoors on a hard-surface court delimited by lines. The ball is smaller than a regular football with less bounce and the combination of playing surface, ball characteristics and rules of the game are held by some to emphasize technical skills. In 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. Similar game tactics are also observed in football and ice hockey. Travassos et al. investigated futsal behaviour in game practice conditions using this game strategy, a condition referenced hereafter as 5-vs-4+GK.

As with previous investigations into dynamical interactions of team sports, the movement trajectories of players were recorded in two-dimensional space and relative phase analysed in both lateral and longitudinal directions. Unlike previous investigations, however, Travassos et al. also recorded ball trajectories. These data enabled the investigation of ball dynamics in game behaviour, which must contain key information given its centrality to game objectives (McGarry, 2009). Relative phase analysis of 5-vs-4+GK futsal game practice reported differ-
Dynamical self-organizing systems

ent strengths of phase attraction for different playing dyads, with general findings of strong in-phase attractions between defenders and ball as well as with each other, and weaker in-phase attractions for the attackers and ball and for attackers themselves. Thus, the defending and attacking dyads produced different coordination dynamics, indicating different playing patterns by way of the different team objectives of defending and attacking the goal, respectively, as well as due to unequal numbers of outfield players between teams (Travassos et al., 2011). As expected, these results were replicated at the level of team interactions too, with increased in-phase attractions furthermore noted for the lateral direction than for the longitudinal one (cf. Lames et al., 2010).

Interactions between players, teams and ball were also subjected to investigation using two separate coordinate systems – those being Cartesian coordinates (x, y), as with previous research, and polar coordinates (angle, radius), referenced to the centre of the single goal being attacked and defended (Travassos et al., in press). In-phase relations between the defending team and ball were stronger than the attacking team and ball for both coordinate systems, with the strongest phase attractions produced using angles indicating ball position in respect to goal location as a key informational constraint for coordinated game behaviour. These results were attributed to the defending team establishing associations with ball and attacking team positions in the context of the goal line. The attacking team, for their part, tended to explore the defending team dynamics by probing for open and opening spaces, and hence possible scoring opportunities, through ball exchanges (passes) primarily in the lateral direction. As noted in Travassos et al. (in press), the relative phase results may be explained by the defending players guarding space in front of goal using zonal defence, thereby positioning themselves with respect to the dynamics of the ball and, to a lesser extent, the attacking players always in reference of the goal being defended. In other words, the defenders position themselves to align on the intercept path between the ball and attacker and the centre of goal. This explanation is consistent with the stronger in-phase attractions reported between defending team and ball in the lateral direction, because changes in ball position in this direction as compared with the longitudinal direction would generally produce increased changes in the angle of ball with respect to the centre goal line. As such, increased attention from the defending team to ball displacements in the lateral direction may be expected, with possibly differing amounts of attention paid by defenders to changes in the longitudinal direction of ball and attackers, depending on whether the ball and attackers are moving to or from goal.

Some final considerations

The general tenet of coordinated behaviours emerging in sports contests as a result of self-organization among coupled oscillators on the basis of shared information exchanges is predicated on universal theoretical principles of open complex dynamical systems. These principles are held as applying across different systems on varying levels of analysis and time scales (Kelso, 1995). That this reasoning should apply to sports contests, then, appears sound in principle, to this author at least, and is furthermore supported by increasing data, but generalizations should nonetheless remain tentative unless and until additional evidence is gathered. For example, each sport is unique, as is each contest within a given sport, and present generalizations from small data samples applied across many different factors (e.g. age, sex, level, sport, small-sided vs full-sided games, practice vs competition, etc.) might be questioned – the argument for universal properties of dynamical systems notwithstanding. Further research is required to address and ultimately resolve these concerns in future.
Concluding remarks

This article has presented gathering evidence in support of dynamical self-organizing principles underpinning game rhythm behaviours in sports practice and sports competition, from research on both individual sports (e.g. squash and tennis) and team sports (e.g. basketball, football and futsal). Coordinated game behaviours are held as self-organizing and resulting from information-based interactions of coupled oscillators (i.e. players and teams). This consideration for sports performance is attractive and, perhaps, compelling in the sense that it permits description of varied game behaviours for different sports by means of common principles. It furthermore accounts for the different game behaviours that characterize these different sports, as well as the unique behaviours that typify individual sports contests. Moreover, this same description applies for different levels of analysis, from displacement to velocity metrics and from radial direction to lateral and longitudinal directions, from player dyads to partial-team dyads to team dyads, from player interactions with the ball to team interactions with the ball, and from Cartesian coordinates to polar coordinates. These findings are interpreted as lending increasing weight to the notion that sports behaviours subscribe to universal principles of complex dynamical systems predicated on information exchanges between coupled oscillators.

References


Dynamical self-organizing systems


