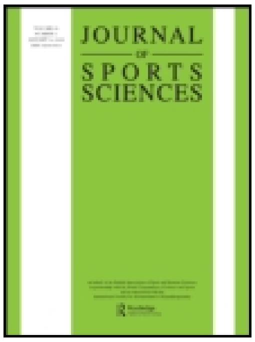

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Sport competition as a dynamical self-organizing system

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The existence of structure in sport competition is implicated in the widespread practice of using the information gathered from a past contest to prepare for a future contest. Based on this reasoning, we previously analysed squash match-play for evidence of signature traits from among the stochastic relations between the various types of shot. The mixed findings from these analyses led us to re-analyse squash match-play as a dynamical system. Here, we extend this line of investigation with some suggestions as to how various sports might be described further within this theoretical framework. We offer some examples of dynamical interactions in dyadic (i.e. one *vs* one) and team (e.g. many *vs* many) sports, as well as some predictions from a dynamical systems analysis for these types of sports contests. This paper should serve to initiate further research into the complex interactions that occur in sport competition.

Keywords: couplings, dynamical systems, self-organization, soccer, sports contest, squash.

Introduction

The last few years have seen considerable research on the performance analysis of sport competition (see Hughes and Franks, 1997, for a review). The initial challenges presented in identifying quantitative measures of sports performance meant that much of the early work was concerned with developing objective and reliable procedures for data collection. The introduction of computer technology facilitated the detailed recording and analysis of sports behaviours and took centre stage in the early development of various notation systems. Thus computer-aided sports analysis systems were designed to record the movements and technical actions of the athlete. What followed was a series of descriptive studies of different sports in various contexts.

The assumption implicit in many of these initial studies was that the recorded variables were relevant to the performance outcome. That is, the system description offered some external validity. Since most sports notation systems were first developed in consultation with a sports expert (e.g. a high standard coach of that sport), the data were considered to possess face validity. The unspoken supposition was that the recorded behaviours yielded invariant features (or signatures) of performance – that is, the data from a past setting extended to a future setting of similar context. On this expectation, the coach would seek to change future behaviours on the basis of information gathered from past performances. From an audit of a sports contest, the coach (or sports analyst) would seek out the critical performance features after first being directed to an identified problem from an initial statistical analysis. For example, a game of soccer was annotated into quantifiable units (i.e. parsed into observable chunks) of behaviour surrounding the juncture points of ball possession and change in ball possession. Within this framework, the defensive and offensive actions were seen as being subservient to the overall goal of retaining and maintaining possession of the ball. Furthermore, each possession was considered as providing an opportunity to fulfil the aims of the game, to score a

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goal. Each behavioural chunk was therefore considered as being of equal importance in realizing the main objective. However, recent research (McGarry and Franks, 1994, 1996; Hodges *et al.*, 1998) has shed doubt on this basic assumption of equal weighting within a general system description of sports performance analysis.

It has long been accepted in sports practice that individuals and teams exhibit unique traits in their playing patterns, which are invariant when viewed against different opponents at different times. Indeed, it is the search for trends in the patterns of play that leads many teams and individuals to 'scout' the opposition. On the basis of such reasoning, McGarry and Franks (1996) analysed shot sequences in international squash contests for invariant relations as expressed in a Markov (probability) chain. In this study, a player's shot selection was analysed as a function of the opponent's antecedent shot, taking into account various classifications for court location. However, we were for the most part unable to find invariant behavioural responses. The squash player instead reacts differently to similar events (shots) when competing against different opponents. Given our inability to identify signatures of performance (i.e. common features of behaviour that span various contests), we began to question the underlying assumption that our system description of sports performance (as indexed using a matrix of recorded technical behaviours) was valid.

In the search for a valid system description, we propose a different account for sports performance analysis. This alternative considers the complex spatial–temporal patterns that characterize a sports contest as a dynamical system.

Self-organizing non-linear systems

The physics of open (complex) systems seeks to explain how regularity emerges from within a system that consists of many degrees of freedom in constant flux. The common thread among various related theories for complex systems (e.g. Thom, 1975; Nicolis and Prigogine, 1977; Soodak and Iberall, 1978; Haken, 1983; Prigogine and Stengers, 1984; Iberall and Soodak, 1987; Glass and Mackey, 1988) is the inherent property of self-(re)organization in response to changes in the elements that comprise the system, or to changes in the constraints that surround the system. In essence, small changes *to* the system can prompt large (non-linear) changes *in* the system as it reorganizes. Kelso, Turvey and colleagues have been instrumental in applying these types of theories to the experimental analysis of perception and action (see Kelso *et al.*, 1980; Kugler *et al.*, 1980). In this paper, we restrict our consideration of sport competition to dynamical principles, even though various other theories of complex systems may assist us in our search for a valid system description. First, we briefly consider the fundamental principles of dynamical systems (for further details on dynamical systems, see Kelso, 1995; for some considerations on dynamical systems as they may relate to various sports issues, see Davids *et al.*, 1994).

One feature that characterizes a dynamical system is the transition in some order parameter (or collective variable) as a result of scaling in some control parameter. The order parameter (cf. dependent variable) is a measure of some kinship between rhythmic individual components that exist within a system. The control parameter (cf. independent variable) is some property that constrains the behaviour of dynamical systems. For example, in quadrupedal gait the phase relation (a spatial measure of where one leg is in respect to another leg throughout a given cycle) has been used as an order parameter (see Schoner *et al.*, 1990) and the speed has been taken as a control parameter. Importantly, the dynamical behaviour is not specified in the control parameter; instead, patterns as expressed in the order parameter are forged and broken as a result of system instabilities brought about through stochastic fluctuations. These random occurrences serve to perturb the system and prompt the non-linear transitions that sometimes occur in dynamical systems. Scaling of the control parameter renders some patterns increasingly unstable, making transitions to more stable patterns more likely. Thus, a horse will change abruptly from a walk to a trot or from a trot to a gallop as a result of increasing its locomoting speed. The source of these particular changes in the order parameters (phase relations) as a result of scaling in a control parameter (speed) is likely to be found in the increased metabolic costs that have been demonstrated to vary for different gaits at different speeds (see Hoyt and Taylor, 1981; see also Kelso, 1984).

In human experiments on dual-limb coordination, Kelso and colleagues (e.g. Kelso *et al.*, 1981; Kelso, 1984; Haken *et al.*, 1985) have demonstrated that the two limbs are coupled in terms of cycling frequency and phase relation. The frequencies and phase relations on which a system tends to settle indicates the presence of frequency and phase attractors, respectively. Well-documented phase attractors for human limb coordination are those of 'in-phase' (i.e. flexion–flexion and extension–extension of limb pairs) and 'anti-phase' (i.e. flexion–extension and extension–flexion of limb pairs). For example, in dual-limb rhythmic tasks, a transition from a starting anti-phase relation to in-phase occurs at some critical point as the cycling frequency is increased. Yet the reverse transition from in-phase to anti-phase does not seem to occur under any conditions, regardless of the cycling frequency and its scaling direction (i.e. whether frequency is increased or decreased). The influence of scaling direction in the control parameter on system transitions is known as 'hysteresis'. This finding of one-way transition for human dual-limb coordination (anti-phase → in-phase) differs in its detail from the two-way transitions for quadrupedal gait (walk → trot → gallop → trot → walk). These differences in detail notwithstanding, the transitions points to and from the various stable regions for quadrupedal gait may still vary as a function of the scaling direction (i.e. hysteresis).

In short, the spontaneous emergence of stable patterns as a result of instability in dynamical systems has provided a useful theoretical premise to explain the brief non-linear phase transitions that occur when the cycling frequencies of human rhythmic actions are increased. Signature features of dynamical systems are thus characterized in a loss of stability as indexed in: (a) an increase in critical fluctuations – variability in the order parameter – pending a phase transition; (b) an increase in critical slowing down after a perturbation (as measured by the local relaxation time – that is, the time for the system to settle back to stability from which it was perturbed) pending a phase transition; (c) non-linear phase transitions in the order parameter with linear increases in the control parameter; and (d) the effects of hysteresis – that is, the dependency of the phase transitions on the pre-existing phase relation and the scaling direction of the control parameter.

The dynamical features of human coordination extend across structure, from couplings within (e.g. Kelso *et al.*, 1991) and between (e.g. Kelso and Jeka, 1992) limbs. Interestingly, these same traits have also been demonstrated to exist between persons. Schmidt *et al.* (1990) studied the dynamical properties of two cooperative people swinging their lower legs (one leg each) in rhythmic harmony and found a repeat of all the major findings of within-person coordination. Yet despite the primary studies of Schmidt and colleagues on inter-person coordination, there has been little research on this topic (see also Foo and Kelso, 2000). And Schmidt *et al.* (1999: 558–559) noted that there has been 'very little research on inter-personal coordination in sport'. In this paper, we begin to consider the coordination tendencies that take place in sports contests in the light of dynamical systems.

Sport competition as a self-organizing system

The nature of a sports contest is competitive and cooperative. In team sports, each player on the same team seeks to coordinate with his or her team members in the pursuit of a common competitive goal. Beyond this, each protagonist – individual or team – cooperates with the other to varying extents at various times. For this reason, sport competition is characterized in a game rhythm that takes one of two forms. Sports contests that alternate possession equally (e.g. tennis, badminton, squash) tend to display a thrust-and-parry (or thrust-and-counter-thrust) activity, whereas sports contests that exchange possession in unequal measure (e.g. hockey, basketball, soccer, rugby football) exhibit a to-and-fro behaviour more reminiscent of a tidal ebb-and-flow. We suggest that the mathematical language of dynamical systems may provide a framework on which to begin to base a formal description for both of these patterned behaviours. To date, such an analysis of sports performance remains in its infancy. In the next section, we report on recent research that sought to examine various aspects of squash contests using dynamical concepts. This first step provides an initial basis on which to predicate a more formal account of sports contests as dynamical systems.

Perturbations in sports contests

Squash

In dynamical systems, a perturbation will sometimes create a transient period of instability before the system returns to its pre-existing state. At other times, a perturbation will lead through the same mechanism of instability to a non-linear transition from one stable state to another stable state. Examples of perturbations in the context of sports performance are ill-defined at present; however, they do cause some imbalance in the system that is being investigated. In squash contests, these perturbations – or imbalances – may result from a well-placed shot that extends the opponent, or a loose shot to open court that allows the opponent to capitalize on the mistake. McGarry *et al.* (1999) analysed squash contests in search of these aforementioned perturbations. The results from two experiments indicated that squash competition might usefully be considered as a dynamical system.

Experiment 1 (*McGarry et al., 1999*). Six experts and six non-experts were asked to view videotape of 60 squash rallies taken at random from various contests. The experimental task was for each independent rater to identify those shots in each rally that they perceived as perturbing (i.e. destabilizing) the rally. Figure 1 presents example data from 8 of 60 rallies for each observer. The solid circle details the shot in the rally sequence that was identified as perturbing the rally from stability to instability. The open diamond denotes the last shot of the rally and hence the length of the rally.

Rally 42 (Fig. 1) indicates a rally sequence of 13 shots, with the sixth shot being identified as a perturbation by all but two observers. In addition, the last observer identified the twelfth shot as perturbing the rally also. Thus, the presence of multiple perturbations in a single rally was possible if the rally settled, or (re)stabilized, at some time after a destabilization (i.e. perturbation). It is notable that unstable dynamical

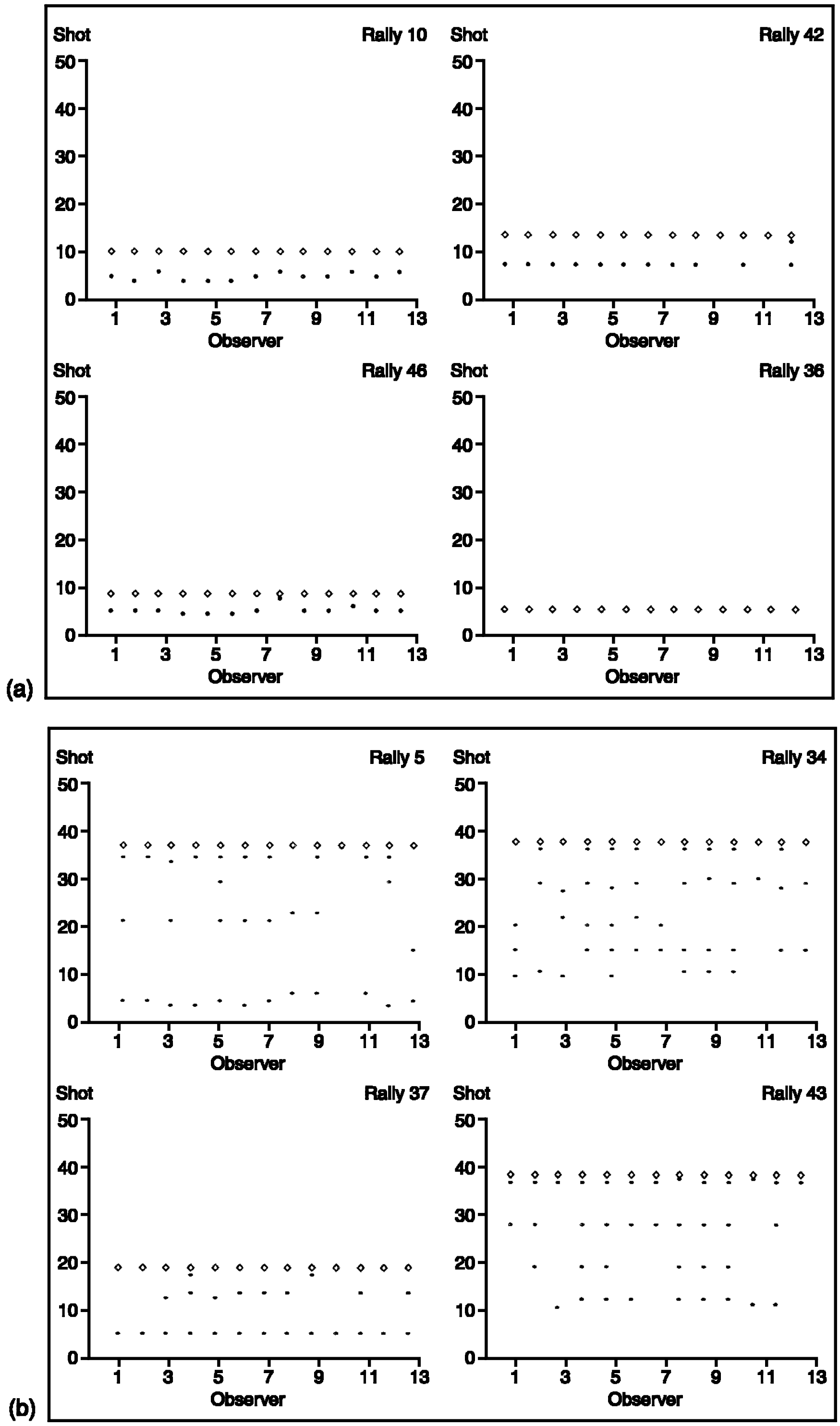

Fig. 1. Shot perturbation onsets for selected rallies. The first observer reflects the agreed-upon judgement of McGarry *et al.* (1999). Observers 2–7 represent the six experts and observers 8–13 the six non-experts. ● = shot perturbation, ◇ = end of rally. Reproduced with permission from McGarry *et al.* (1999).

systems may return to pre-existing stable regions or otherwise transit to other stable regions; however, distinctions between alternative regions of stability for sports contests, including squash contests, have yet to be made. The solid squares that lie on a horizontal line across the range of observers (see rally 42) indicate high inter-rater agreement on the identity of the shot perturbation and, by extension, the state of the rally in general – stable or unstable. Figure 1 indicates good inter-rater agreement for each participant for each rally. This good inter-rater agreement includes rally 36, in which no shot perturbation was identified by any observer. Statistical analysis of the entire set of 60 rallies using the kappa coefficient revealed high inter-rater agreement between experts and non-experts alike, although a significant difference between experts and non-experts was reported, as expected. These results were taken as validating the perception of transient instabilities in squash match-play.

Experiment 2 (*McGarry et al., 1999*). The x-y data for each player were collected from 4 of 60 squash rallies using perceptual tracking. Each player was tracked separately from a video screen and the images projected onto a graphics tablet, whose x-y coordinates were sampled at 100 Hz (see McGarry *et al.*, 1999, for further details). The x-y data for each player were analysed to determine the radial distance of each player from the 'T'-position (i.e. centre-court) at any instant after first synchronizing the data to the onset of the rally. The time-locked radial data for the two players within a given rally revealed a strong anti-phase relation. Figure 2 provides an example taken from one of the four rallies of McGarry *et al.* (1999). These data were interpreted to indicate a highly damped mono-stable dynamical system with a single anti-phase attractor onto which system fluctuations are occasionally written.

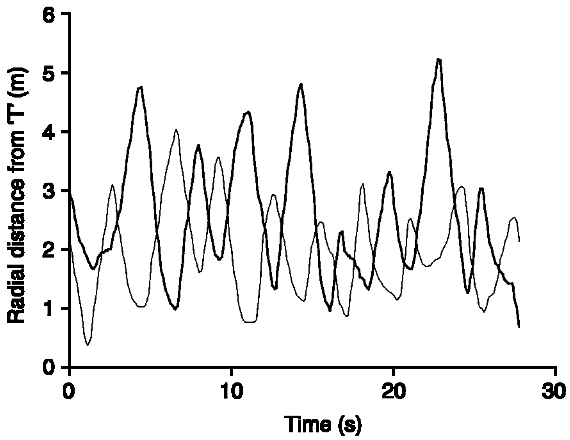

Fig. 2. Radial distance from the 'T' of the server (bold line) and receiver (thin line) synchronized in time. Reproduced with permission from McGarry *et al.* (1999).

Taken together, the data from these two experiments suggest that the patterns of organization observed in dyadic sports (squash match-play) display characteristics of dynamical systems. Specifically, the ability of independent observers to identify shot perturbations in squash match-play lends support to the notion that the system can be perturbed from some stable or near stable state. Furthermore, evidence of multiple perturbations shows that the system does recover from instability in some cases, and reverts again to stability, as evidenced by the next perturbation in the same rally. This finding, together with the result that a shot perturbation usually precedes a rally outcome (winner, error or let), forces a distinction between stability and instability in the description of squash match-play. It would appear, then, that the shot perturbations that lead to system instability are key athletic behaviours in determining the outcome of a rally. Under this alternative system description, questions of concern for the coach and athlete include: What was the cause of the perturbation? How did the athlete react to the perturbation? What was the effect of the perturbation on the stability of the system?

Soccer

The notion that a perturbation may lead to a disruption in sports behaviour has been analysed in soccer as well as squash (see Gréhaigne *et al.*, 1997, for a related consideration of the changing configurations in soccer). Hughes *et al.* (1998) defined a perturbation in soccer as an incident that changes the rhythmic flow of attacking and defending, leading to a shooting opportunity. For example, a perturbation could be identified from a penetrating pass, a dribble, a change of pace or any skill that creates a disruption in the defence and allows an attacker a shooting opportunity. In some cases, a perturbation of the defence may not result in a shot, owing to defensive skills or a lack of skill in attack. This reasoning supposes that the defending team looks to restabilize the just destabilized system, in effect dampening or 'smoothing out' the disruption caused by the perturbation. If a perturbation should result in a shooting opportunity, then this event is termed a 'critical incident'. Using this definition of a perturbation, Hughes *et al.* (1998) reported significant differences in the goal to perturbation ratios between successful and unsuccessful teams in the 1996 European Championships.

The above analysis supposed that a critical incident (a shot on goal) must be preceded by a perturbation – that is, some aspect of skill, good or bad, that disrupted the normal rhythm of the game. Thus, by tracing back from the shot on goal, Hughes *et al.* (1998) found that, as expected, the perturbations could be reliably identified. In the next step, Hughes *et al.* (2001) confirmed that perturbations could be reliably identified in soccer without recourse to the method of 'back-tracking' from a shot at goal. They designed a hand notation system and, after appropriate training, recorded a match on three separate occasions. Sufficient time between recordings was allowed to negate learning effects. An intra-rater analysis of variance (ANOVA) on three sets of data taken from the same match produced a coefficient (R) of 0.891, indicating that the perturbations were identified consistently.

After the reliability analyses, Hughes *et al.* (2001) selected 15 matches at random for analysis from the 1996 European Championships. The aim of their study was to identify the skill variables that led to the 'smoothing out' of some of the identified perturbations. [Recall that, in the definition of Hughes *et al.* (2001), a perturbation may or may not result in a critical incident, that is a shot on goal.] The detailed analyses of these matches were summarized in three categories: player in possession, defensive actions and intended recipient actions. The variables for smoothing the perturbations were sub-categorized under the three main causes:

- *Player with the ball*: overweighted pass, inaccurate pass, mistimed pass, player fouled after delivery of pass, player tackled at point of delivery of pass.
- *Interceptions*: interception of pass, deflection of pass, pass headed away.
- *Receiver*: tackled at the point of reception, fouled on the ball, fouled before receiving the ball, loss of control, defensive header, mistimed run.

Data collection took the following form. When a shot took place, the tape was rewound to the beginning of the team's possession and the time noted. The position on the field and the number of the player were recorded, together with the action taken. When the passage of play had been analysed, the tape was again rewound to the start of the team's possession. From observing the move again, a skill that would cause a possible perturbation could be determined; the perturbation and time it occurred was recorded, together with the passage of play.

The most frequent action variables for smoothing out the perturbations were those associated with the player being in possession of the ball (47%) as well as those made by the defensive players (41%). An innacurate pass by the player in possession accounted for 62% of the passing variables. Relatedly, an interception by the defence was strongly linked with the frequency of inaccurate passes and was the most frequent of the defensive actions (68%). The actions of recipients were comparatively less frequent (12% total). Nevertheless, the actions of recipients are very important given their proximity to the critical incident, a strike on goal. The most common action of the recipient players was a loss of control. Hughes *et al.* (2001) concluded that, by identifying the actions that nullify the perturbations in soccer, it was possible to give teams specific profiles of variables that identify winning and losing traits.

Intra- and inter-coupling among players in dyadic sports

In the sub-section on 'Perturbations in sports contests', we reported initial analyses of the dyadic interactions in squash contests from the standpoint of dynamical systems. Such sports as badminton contain doubles play and permit an extension of this type of analysis. This line of reasoning can be extended further to consider interactions in team sports that consist of many players; see the next sub-section for further details. For doubles play, we posit the existence of two couplings. We distinguish between couplings among players *within* a doubles pair and couplings among players *between* a doubles pair using the terms 'intra' and 'inter', respectively.

Each doubles pair in badminton or tennis forges links in the pursuit of a common aim, be it to defend their half of the court or to attack the opposing pair's half-court. The aims for each doubles pair will alternate as possession of the shuttlecock or ball is traded. For instance, in doubles badminton, each pair will tend towards a 'front–back' intra-coupling when attacking and a 'side-to-side' intra-coupling when defending. We suggest that the hypothesized perturbations in badminton (perturbations in sports contests other than squash and soccer have yet to be documented in the scientific literature) might be reflected in atypical changes in these intra-coupling relations.

The inter-couplings that exist in doubles badminton and tennis would also be expected to provide important information for a sports contest. Inter-couplings can take place between players (a player in a doubles pair interacts with a player in the opposing pair) as well as between doubles pairs (a doubles pair interacts with the opposing doubles pair). These types of couplings are not fixed, but instead are constantly being formed and broken. These new considerations of dynamical interactions between functional dyads in sports contests point to a new direction for research on sports performance.

Intra- and inter-coupling among players in team sports

Here, we extend our consideration of intra- and inter-couplings to team sports. We suggest that the rich and varied patterns that arise in team sports are the result of self-organization among many coupled oscillators (i.e. players). These couplings should be considered as prey to the competing effects of maintenance and magnetism (cf. von Holst, 1939). We will retain our previous nomenclature of 'intra' and 'inter' to distinguish between couplings among players within a team and couplings among players between teams, respectively.

Figure 3 presents some hypothesized intra-couplings for the ten outfield players (goalkeeper excluded) in a soccer team. In this example, the first team (upper half) uses a 4-4-2 formation (i.e. four defenders, four midfielders, two attackers) and the second team (lower half) a 3-5-2 formation. Each defender (D), midfielder (M) and attacker (A) is coupled with their immediate neighbour in both the horizontal (dashed line) and the vertical (solid line) relation. These intra-couplings are presented by way of example only and should not be considered as either exclusive or exhaustive. Nor should these same intra-couplings be viewed as inflexible. Instead, the various intra-couplings will be forged and broken at will (or lapse) as the context of the game demands. Similarly, inter-couplings (not shown) consisting, say, of attacker–defender, midfielder–midfielder and defender–attacker interactions will also be forged and broken constantly as each team intermingles with the other in their contest for possession of the ball. We hypothesize that the flexible and varying intra- and inter-couplings of temporary association give form and function to such sports contests.

The intra- and inter-couplings suggested above would be expected to occur within local constraints as a result of game tactics. For instance, one aim of each player and team is to free-up space when possession is won and to tie-up space when possession is lost. This important duality of purpose, which bifurcates as possession is won (i.e. attack) and lost (i.e. defend), operates among various playing units, from the individual through to the whole team. Importantly, these intra- and inter-relations may attract (cf. forge) or repel (cf. break) at various times as the players cooperate and compete for possession of the ball or space. In this sense, the ball may be thought of as an attractor onto which the behaviour of each player and coupling is anchored.

Some predictions for the analysis of sport competition as a dynamical system

We present some additional dynamical examples from dyadic and team sports, together with some predictions for their subsequent analysis. The idea that a sports contest can be analysed as a non-linear self-organizing system that is grounded in dynamical principles gives rise to a few predictions. Simply put, these predictions (see below) hold that the signature features of dynamical systems as listed earlier be evident in sport competition.

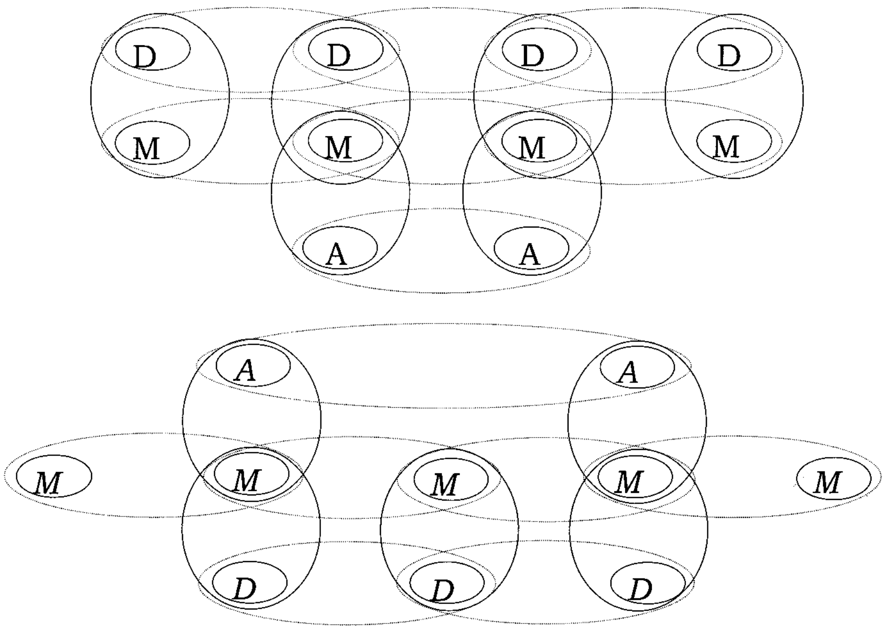

Fig. 3. Some possible intra-couplings for two contesting soccer teams. The first team (upper half) is using a 4-4-2 formation and the second team is using a 3-5-2 formation. D = defender, M = midfielder, A = attacker. See text for further details.

Sports contests should be described in terms of order and control parameters

Identifying the order parameters in a given sports contest is fundamental if the system is to be described as dynamical. In dyadic sports, the relative phase between the two players offers itself as a possible order parameter. This would, of course, require some coupling between the players, each of whom would exhibit a tendency to oscillate around a given point or locus. This 'locus of oscillation' may be public or private. In squash match-play, we would consider the locus – the 'T' – to be public, given that each player competes for ownership of the same space. The locus may also be public for badminton and tennis. On the other hand, the locus may be private for these sports, given that each player competes for ownership of their defending space (their own half of the court) in the first instance and for ownership of the attacking space (their opponent's half of the court) in the second instance. Thus the centre of each half of the squash court – or the centre of each baseline for tennis – offers itself as a potential private locus for these sports. Regardless, once a public or private locus is identified for a dyadic contest, then the relative phase of the coupled oscillators (players) comprising the dyad may be analysed using the radial distance of each player as in our treatment of the squash match-play data (cf. Fig. 2).

The flow of energy is key in the restructuring of any complex system. For instance, a horse changes its gait pattern to minimize its energy expenditure of any given speed (cf. control parameter) (Hoyt and Taylor, 1981). With this constraint in mind, McGarry *et al.* (1999) suggested a physiological attractor for sport competition that serves to draw the system towards a state of homeostasis or stability. This supposition is supported in the findings of intermittent exchanges in stability and instability in squash match-play (McGarry *et al.*, 1999). Sedate cooperative exchanges in squash rallies would be predicted to exhibit stable anti-phase relations at low frequencies as each player tries to attain or maintain an aerobic state. Non-sedate competitive exchanges, on the other hand, might be expected as one or both of the players makes repeated high-frequency excursions to and from the 'T' as part of a physical strategy of anaerobic taxation by either or both players. Slight phase deviations from anti-phase may well accompany these high-frequency excursions as the rally is destabilized.

One expert rater in the study of McGarry *et al.* (1999) commented that squash players are either 'actors' or 'reactors'. Actors are more likely to initiate a perturbation and to destabilize the dyad, whereas reactors are more likely to respond to a perturbation and to restore the dyad to some semblance of stability. In such a thrust-and-parry exchange, we would predict a control advantage to the player with the lead phase relation (the actor) over the player with the lag phase relation (the reactor), an advantage that should materialize in the long run as a winning outcome. However, squash players place a strong reliance on safe defensive play, a tactic that may yield a control advantage to the reactor instead of the actor. These predictions have yet to be investigated using field observation.

Team sports yield complex patterns that pose a much larger problem than dyadic sports in suggesting a relevant order parameter. Irregular and varied periodicities in team behaviour would be predicted from the coupling and de-coupling of many oscillators (see von Holst, 1939, for an example of the complex behaviours derived from three coupled oscillators). The level and time-scale of the analysis are thus critical if team sports are to be described in dynamical terms.

We suggested earlier that team sports are the composite of myriad coupled dyadic intra- and interactions (cf. Fig. 3). Schmidt *et al.* (1999) provided an interesting example of this thinking in describing a backdoor play in basketball. The backdoor play involves an attacker moving forward a step or so towards their own basket before promptly turning around and exploiting the space just created behind the ensuing defender who has become too close to their mark. In this example, Schmidt *et al.* speculated on the distance of the attacker or ball from the attacking basket and the distance between the defender and the attacker as possible order and control parameters, respectively.

The example from basketball is of an attacker trying to free space from a defender using a 'backdoor play'. In soccer, a similar example would be of a player in possession of the ball trying to free space from their immediate marker using a feint technique. In this example, the marker is sent in the direction of the feint, for example to the left, while the player in possession of the ball takes the vacant route just fashioned (i.e. to the right). Variant examples on the same theme would be of a player not in possession of the ball acting as a decoy to free space for a team member. Such examples are commonplace in sport competition. In rugby football, wingers will try to outpace their intercepting marker (i.e. the fullback) in a race to the try line. In the event of a pending interception before the try line can be reached, the winger may try to outwit the fullback by breaking step. This break of step may then allow the winger to sidestep the already committed fullback or to outflank the fullback by a turn of pace once the fullback has become flat-footed on account of adjusting to the winger's break in stride. The running back may try to gain the important extra yard from the defender in American football using a similar technique.

The examples detailed above can be described by attacker–defender symmetry. The attacker or 'actor' strives to break symmetry at opportune times, whereas the defender or 'reactor' in contrast tries to preserve or restore symmetry at all times. The duality of purpose identified earlier means that each player alternates in the role of actor and reactor as the game context demands. In this way, the game may be thought of as living in the regions of meta-stability (see Kelso, 1995), where individual actions may serve to destabilize or (re)stabilize the system accordingly. The facility with which an attacker or a defender may destabilize or (re)stabilize the system would be considered a hallmark of quality in sport competition. In general terms, the ability of a team to destabilize or (re)stabilize a system might be examined at critical junctures of a soccer game, say on the occurrence of an unexpected change of ball possession. An analysis of the relative positions of attacking and defending players at the instant of that change, compared with some time shortly thereafter once the defence has had time to reorganize, might yield useful information in this respect.

Whether these examples from team sports can be described using the same order and control parameters as suggested for dyadic sports remains to be established empirically. The distance between the attacker and their intended goal as well as between the attacker and the defender offer themselves as candidate order and control parameters, respectively (cf. Schmidt *et al.*, 1999). If the relative phase between the attacker and the defender is to be the order parameter, then the first task is to identify the coupled oscillations around a given locus or loci. The second task is to identify couplings between couplings (cf. badminton doubles, p. 776), since it is these types of higher-order interactions that are hypothesized to create the complex game rhythms that characterize team sports. This second task is very challenging and will give rise to complex periodicities. One method would be to investigate various hypothesized couplings using computer analysis in an effort to recreate the structures that are perceived within any given sports contest. Even so, the absence of a lawful system description remains a problem if the empirical and artificial (computer-generated) structures are to be later contrasted for the necessary purposes of validation.

Sports contests should exhibit a general tendency to stability

Sport competition should demonstrate a tendency to stability if it is to be consistent with a dynamical system. Stable regions of a system are readily distinguishable from each other by non-linear changes in the order parameter that results from the linear scaling of a control parameter. In the absence of identified order and control parameters, one way of identifying stability in a given system is to infer its existence from those instances of system instability or transition. On this reasoning, McGarry *et al.* (1999) sought to identify shot perturbations in squash match-play using human raters in the first instance. Similarly, Hughes and colleagues have reported on perturbations in soccer. McGarry *et al.* (1999) later sought to begin to characterize the same squash system using relative phase as a possible order parameter and to determine whether change in the order parameter corresponded with a rally perturbation as detected by the human raters. Their findings – from four rallies only – did not indicate a good correspondence. In summary, further research aimed at identifying stability and instability in sports contests is required. We suggest the stereotypical examples of broken symmetry that we described earlier as a possible starting point.

Sports systems may or may not exhibit increased variability (i.e. instability) before any non-linear transition in behaviour

One feature of dynamical systems is an increase in variability in the order parameter as a precursor to a non-linear transition. In addition, the critical slowing down of the system would also be predicted to increase as the system nears a pending transition. These predictions hold when the control parameter is scaled without the influence of intentional constraints (cf. Haken *et al.*, 1985). In contrast, a rapid scaling of the control parameter, or an intentional constraint to switch or not to switch (i.e. to resist switching), would be expected to reduce, although not remove, these intrinsic dynamics (Scholz and Kelso, 1990). The impact of intentional constraints on the intrinsic dynamics of sport competition will require further investigation.

Sports systems should be viewed in light of a developmental perspective

Systems that exhibit dynamical tendencies are held to do so regardless of the level and time-scale at which the system is analysed (Kelso, 1995). In this paper, we chose to restrict our focus to the kinematic relations between players (level of analysis) within a sports contest (time-scale). Extending the level of analysis and time-scale to a series of sports contests in the course of a season would offer additional information for our understanding of sports performance. Thus, the fortunes of a player or team over a series of contests might itself be considered as a dynamical system on a different level of analysis and time-scale from that considered hitherto. From a developmental perspective, changes within the players that comprise a series of sports contests would be considered agents for change within a dynamical system. In the course of a season, there may be variations in, for example, the injury status, fitness and skill of players and, for team sports, the availability and selection of players. Thus, the attractor landscape that underpins the intrinsic dynamics of any given sports contest may itself change over the course of a season or more as a result of change in these and other variables. The impact of developmental variables on the intrinsic dynamics of a sports contest is an important issue that future research should address. First, however, the sports contest must be described in dynamical terms (i.e. order and control parameters) if the attractor landscape is to be mapped.

Conclusion

We have searched for a lawful system description of the spatial–temporal relations that characterize a given sport contest. Various examples of player–player interactions are presented from dyadic and team sports, together with some suggestions for their analysis as a dynamical system. This paper reflects the growing body of work in this area. Although there is still debate over whether perturbations can be defined and identified in a sports context, attempts have been made in both squash and soccer. Once this debate is settled, the benefits of analysing perturbations in sport should make the analyses more critical and more dynamic, thus enhancing its support of the coaching role. Our hope is that this paper will serve to foster research efforts that strive to describe formally the complexities of the behavioural interactions that give rise to form and function in sport competition.

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