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Space–time coordination dynamics in basketball: Part 1. Intra- and inter-couplings among player dyads

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Abstract

We examined space–time patterns of basketball players during competition by analysing movement data obtained from six game sequences. Strong in-phase relations in the longitudinal (basket-to-basket) direction were observed for all playing dyads, especially player–opponent dyads matched for playing position, indicating that these movements were very constrained by the game demands. Similar findings for in-phase relations were observed for the most part in the lateral direction, the main exception being dyads comprising the two wing players from the same team. These dyads instead demonstrated strong attractions to anti-phase, a consequence perhaps of seeking to increase and decrease team width in tandem. Single instances from select dyads and game sequences demonstrated further evidence of phase stabilities and phase transitions on some occasions. Together, these findings demonstrate that space–time movement patterns of playing dyads in basketball, while unique, nonetheless conform to a uniform description in keeping with universal principles of dynamical self-organizing systems as hypothesized.

Keywords: *Patterns, couplings, dyads, dynamical systems, interpersonal coordination*

Introduction

Gathering scientific data on athletic behaviours in an attempt to improve sports performance has gained widespread acceptance in the sports community (for a review of 25 years' sports performance research published in this journal, see Nevill, Atkinson, & Hughes, 2008). The general approach has been to use performance metrics, sometimes referred to as "indicators" or "profiles", to measure sports behaviours for the purpose of assessment and investigation. A drawback of this approach, however, is that the specifics of the opponent tend to be overlooked when assigning performance metrics to a player or team, even though the opponent influences those same performance metrics (McGarry & Franks, 1996a). For example, a strong or weak profile awarded to a player or team will take from or give to the performance measure of the opponent, and vice versa, by virtue of their interactions (McGarry & Franks, 1996b). These comments apply more to interactive sports such as squash, tennis, basketball, and soccer than to less interactive sports such as track and field, gymnastics, and golf.

The performance of a player or team might not therefore be reduced to analysis without regard for the opponent. Instead, performance might be better contemplated as the result of interactions of players and teams, with the interactions being considered as indivisible for the purpose of analysing game behaviours. Such reasoning prompted McGarry and Franks to consider a squash contest, as well as other sports contests, in terms of a complex dynamical system, specifically one in which the rhythm of the game was proposed to change intermittently between periods of stable and unstable behaviours (for further details, see McGarry, Anderson, Wallace, Hughes, & Franks, 2002; McGarry, Khan, & Franks, 1999). Importantly, the behaviour of a complex system emerges as a result of self-organization among the interacting parts of which the system is comprised, such as the players in a sports contest. Others also have considered sports contests as complex systems (Davids, Araújo, & Shuttleworth, 2005; Lames, 2006; Reed & Hughes, 2006).

The intra- and inter-couplings of playing dyads has been proposed as the basis for space–time patterns in many different sports (McGarry et al., 2002). Here, intra-coupling refers to the linkage between two

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players from the same team and inter-coupling to the linkage between two players from opposing teams. Individual (one vs. one) sports thus comprise a single inter-coupling between two opponents, whereas team sports (many vs. many) offer the possibility of multiple dyads comprising both intra- and inter-couplings. The idea of couplings and their layerings (i.e. the coupling of couplings) suggested by McGarry et al. (2002) offers the prospect of an underpinning description for many different sports predicated on the unifying principle of self-organizing dynamical principles. Evidence for the viability of this type of system description comes from non-team sports including squash (see McGarry, 2006; McGarry & Walter, 2007; McGarry et al., 1999) and tennis (Palut & Zanone, 2005) and, more recently, team sports such as small-sided soccer (Frencken & Lemmink, 2008). In this article, we advance this line of research by analysing the intra- and inter-couplings of player dyads in basketball as a dynamical system.

Methods

The present study was conducted in accordance with standard research practice in France and the guidelines outlined in the Canadian Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans.

Data collection

The data were recorded in 2008 during a men's professional basketball game in France using a digital camera (frequency = 25 Hz) located 15 m above and to one side of the long axis of the basketball court. Several sequences of play of sufficient duration to exhibit intermittent changes in ball possession were then identified, of which six were selected at random for movement analysis. Figure 1 provides a description of the game score dynamics (upper panel), the location of the data sequences extracted with reference to the game score (upper panel), and a description of the important game events within these sequences (lower panel).

Data processing

For reference, each player was identified by team (A or B) and position (1 to 5), where 1 represents the point guard, 2 the shooting guard (wing player), 3 the small forward (wing player), 4 the power forward, and 5 the centre.

The movement data for each player were obtained separately in sequential fashion. First, a given player was marked from head to foot as an elliptical object using Dartfish Darttrainer Teampro software for automatic tracking throughout the game sequence. Following data collection, the pixel data from the centre of the ellipse were then subjected to data processing using a second-order 1-Hz low-pass Butterworth filter before transformation to pitch coordinates using planar geometry.

The centre of the ellipse was assumed to provide a good approximation to court location for a given player. This assumption was not verified empirically but nonetheless seemed reasonable from visual inspection of two-dimensional reproductions of player movements using point-light displays complete with court markings and basket locations.

The bottom left corner of the basketball court, as viewed in the video image, was assigned zero coordinates. The location of the video camera, together with our preference for considering basket-to-basket game play in the longitudinal direction, means that the x and y axis represent the longitudinal and lateral direction, respectively.

Intra-rater assessment

The pre- and post-data for all players taken from a 30-s segment from one of the six game sequences were analysed to assess accuracy and reliability using the technical error of measurement (TEM) and coefficient of reliability (*R*), respectively (for additional information, see Goto & Macie-Taylor, 2007). The intra-TEM ($\text{TEM} = \Sigma D^2/2N$, where D is the difference between the pre and post measures and N is the sample size) and intra-%TEM ($\%\text{TEM} = 100 * \text{TEM}/X$, where X is the grand mean of the pre and post measures, i.e. $X = [X_{\text{pre}} + X_{\text{post}}]/2$) yielded values of 0.198 m (1.328%) and 0.217 m (2.342%) for the longitudinal and lateral data, respectively. In addition, the coefficient of reliability ($R = 1 - [\text{TEM}^2/\text{SD}^2]$, where SD is the standard deviation of all measures) produced values of 0.999 and 0.967 for the longitudinal and lateral data, respectively.

Results and discussion

Relative-phase: Intra- and inter-coupling among dyads

Figure 2 presents the movement data for the player–opponent dyads from the third data sequence. The A_1-B_1 dyad is represented in the upper pair of panels, the A_2-B_2 dyad in the next upper pair of panels, and so on. The left and right panels present the longitudinal and lateral data, respectively.

Visual inspection of Figure 2 demonstrates oscillatory movement patterns in both the longitudinal and lateral direction, with each dyad traversing the court in lockstep fashion for the most part, particularly in the longitudinal direction as the game proceeds from basket to basket (Figure 2). However, the A_4-B_4 dyad

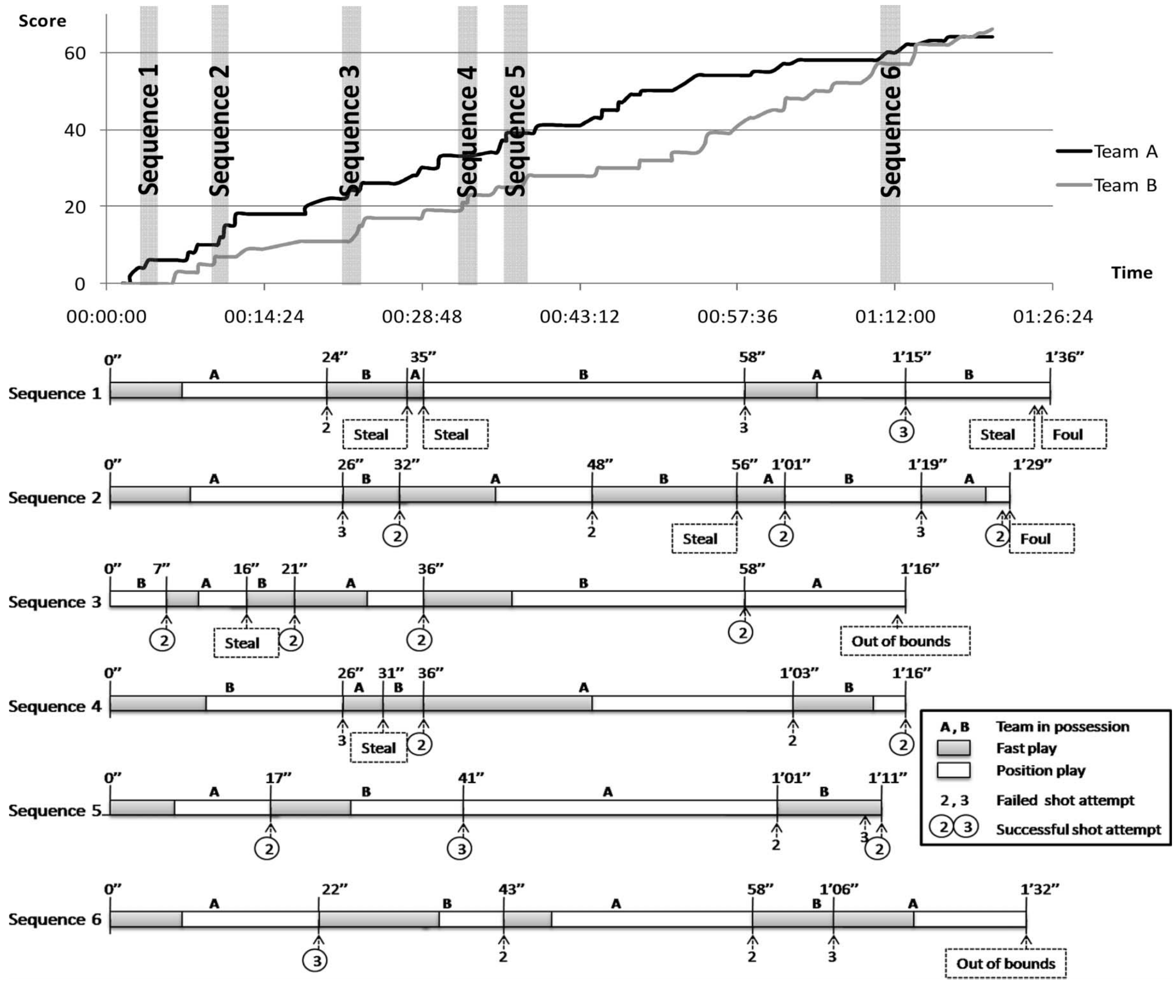

Figure 1. Time line of the changing game score and location of the data sequences extracted for analysis (upper panel). The individual data sequences and the time line of important game events, including team in possession, type of play, shot attempts, steals, fouls, and out of bounds (lower panel).

(left panel) deviates markedly from this lockstep arrangement (approximately 15 s), with one player (A_4) not returning with his opponent (B_4) to the other basket for some reason. Similarly, the A_5-B_5 dyad did not return to the open basket, whereas the other three dyads (A_1-B_1, A_2-B_2, and A_3-B_3) did. Further investigation of this game sequence showed that a "steal" from A_4 by B_4 occurred at 16 s (Figure 1, lower panel), resulting in a fast counter-attack with a numerical advantage to the attacking team (B) culminating shortly thereafter in a 2-point basket. The A_5-B_5 dyad decided not to participate in this particular counter-attack for some reason. Indeed, from the perspective of B_5 it would seem appropriate not to participate in the counter-attack given that A_5 (and A_4) remained in their advanced positions, thus offering the possible option to their team of a fast break following a restart in game play.

The longitudinal and lateral data for all dyads and all game sequences were subjected to relative-phase analysis using the Hilbert transform (Palut & Zanone, 2005). The relative-phase data were then forced into -180° and 180° limits before presentation using histogram analysis (Figure 3). The upper panel represents the relative phases for the longitudinal data and the lower panel the relative phases for the lateral data.

The longitudinal data demonstrate strong attractions to in-phase and strong repulsions from anti-phase. The lateral data demonstrate a more varied phase distribution for the dyads with weaker attractions to in-phase and, notably, a second attraction to anti-phase. Since the phase distributions comprise all of the intra- ($N = 20$, 10 per team) and inter-dyads ($N = 25$), it is unclear whether the individual dyads are themselves bi-stable in the lateral direction and therefore switch intermittently between in-phase and anti-phase, or whether they are mono-stable with some dyads demonstrating properties of in-phase and others anti-phase with no switching between these two states. Further analysis revealed evidence for the latter interpretation. In particular,

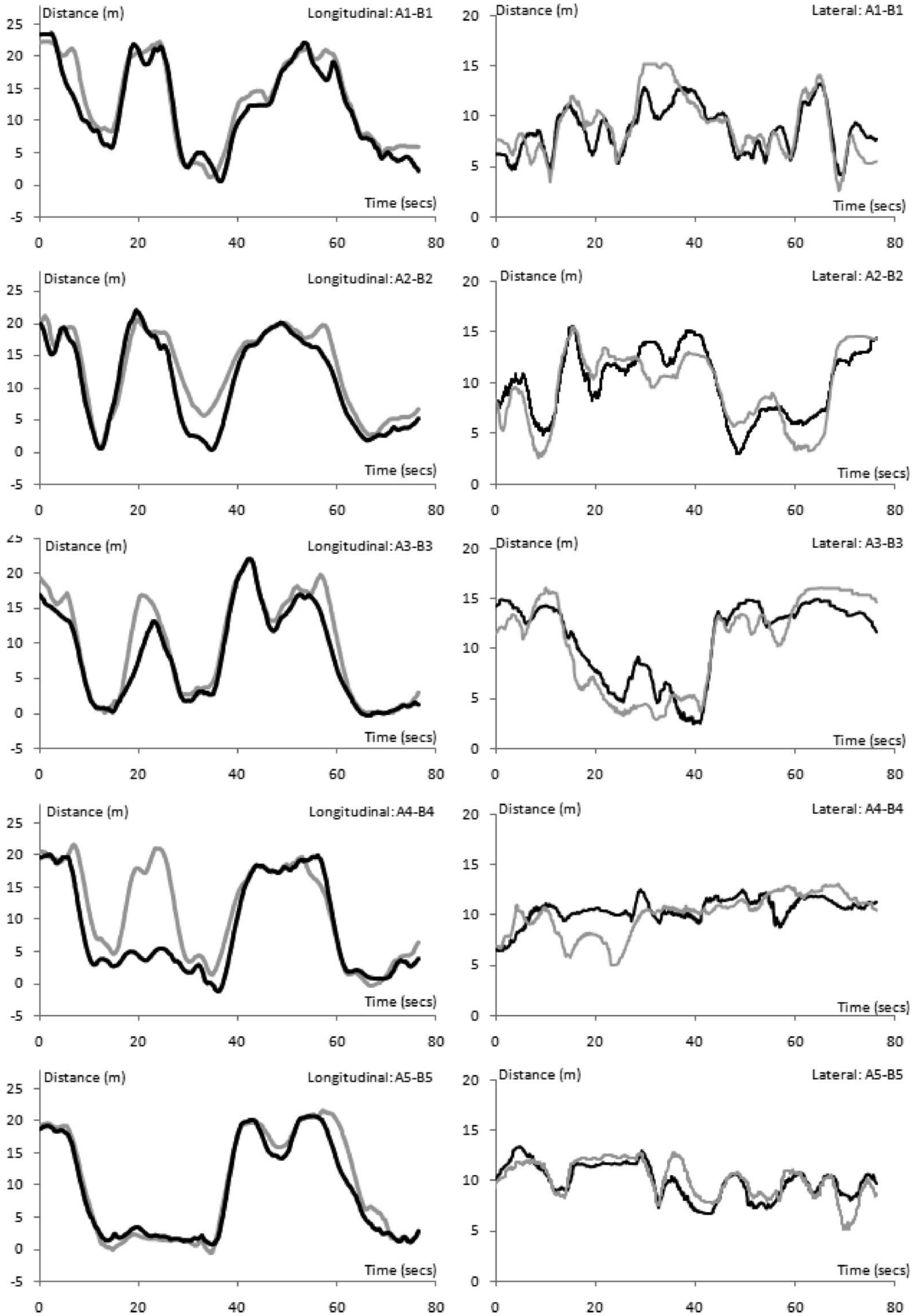

Figure 2. Unfiltered data of displacements of the ten basketball players for the third sequence (1 min 16 s) in the longitudinal and lateral directions. The displacements of the players on Team A and Team B are represented by black and grey lines, respectively.

the player–opponent dyads accounted for much of the in-phase peak, and the A_2-A_3 and B_2-B_3 dyads were responsible primarily for the anti-phase peak. In the next subsection, we report additional analyses of the intra- and inter-dyads for the lateral direction only.

Relative-phase: Lateral displacement

Figure 4 presents the phase relations for each of the player–opponent dyads matched on playing position ($N = 5$). These data demonstrate strong attraction to in-phase for the player–opponent dyads but the strength of this attraction weakens considerably as

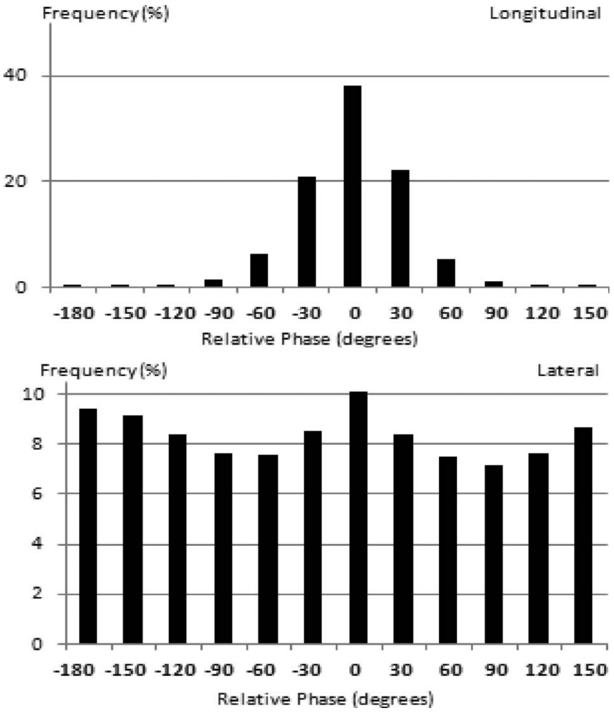

Figure 3. Frequency histograms of the relative-phases of all possible basketball player dyads using separate measures of longitudinal and lateral displacement.

number of player position increases. A major function of basketball positions 4 and 5 is defensive, as exemplified in tasks such as competing for ball possession on the rebound following a missed basket attempt from the opponent, and acting as a second defender in support of team-mates. Thus, the basketball duties required of these players by virtue of their playing position require them to form dyads with the opposing player albeit with weaker, or more flexible, couplings than those for the other player–opponent dyads.

Figure 5 depicts select phase relations (left-hand panels for team A, right-hand panels for team B) from some of the player–player dyads. Visual inspection demonstrates that the relative-phase patterns for a dyad are specific to certain positions and, in some instances, specific to a given team. First, we consider the couplings observed in common between the two teams and then the couplings unique to each team.

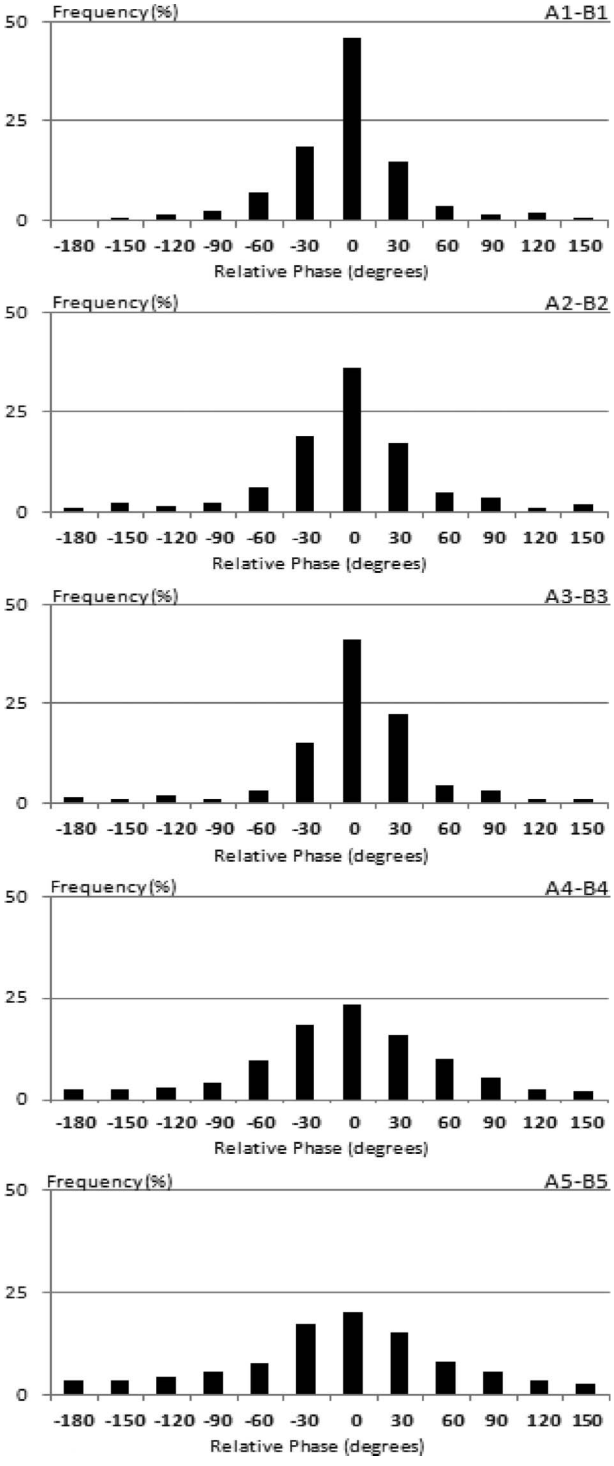

Figure 4. Frequency histograms of the relative-phases of player–opponent dyads using lateral displacement. The identity of the dyad is located in the top right-hand corner of each panel.

The A_1-A_5 and B_1-B_5 dyads (upper panels) demonstrate similar phasic properties, suggesting common dyad couplings based on position, a possible consequence of long-accepted basketball strategies, well-established game playing habits, and so on. In particular, the bi-modal distributions for A_1-A_5 and B_1-B_5 with attractions of –150° and 90° suggests a complex space–time pattern between these team players. Similar patterned relations across teams were demonstrated for the A_2-A_3 and B_2-B_3 dyads (second panels), with strong attractions to anti-phase (more pronounced for team A than team B) being accompanied by strong repulsions from in-phase. The strong attraction to anti-phase for both teams is consistent with the positional demands of the wing players noted previously, generally being to increase width when attacking and to reduce width when defending.

The A_3-A_4 dyad (lower left-hand panel of Figure 5) presents evidence of a phase relation that indicates an attraction towards $-45°$. From this finding we deduce the presence of a lead–lag relation in the A_3-A_4 dyad, an observation that is consistent with previous sports performance analysis in squash (McGarry, 2006; McGarry et al., 2002) and tennis (Palut & Zanone, 2005). Given that Player 3 was taken as the referent signal in the A_3-A_4 dyad, we determine that Player 3 leads Player 4 by one-eighth of a cycle (45°) or, alternatively, that Player 3 lags behind Player 4 by seven-eighths of a cycle. This interpretation might be explained by the fact that the power forward (Player 4) rarely exhibits leading behaviours in team coordination, not least because of few ball possessions, and is therefore more likely to follow the play of other team members. However, it should be noted that the lead–lag phase relation of A_3-A_4 was not observed for B_3-B_4 (lower right-hand panel), who instead did not appear to experience attractions to any particular phase relation of note. Importantly, this finding demonstrates that certain phase relations are not necessarily a given for any given dyad. Instead, they are the result of coupled information exchanges among particular dyads. Similar comments regarding the uniqueness of different dyads apply to the A_2-A_4 and B_2-B_4 dyads also (next to lowermost panels).

In general terms, Team A exhibited more distinct intra-coupling phase relations than Team B. This result might indicate that Team A was more patterned in its behaviours, thereby offering the possibility of Team A being more dependent on a preconceived game plan, as determined from its *a priori* game strategies, its practice routines for offensive plays, and so on. In contrast, the behaviour

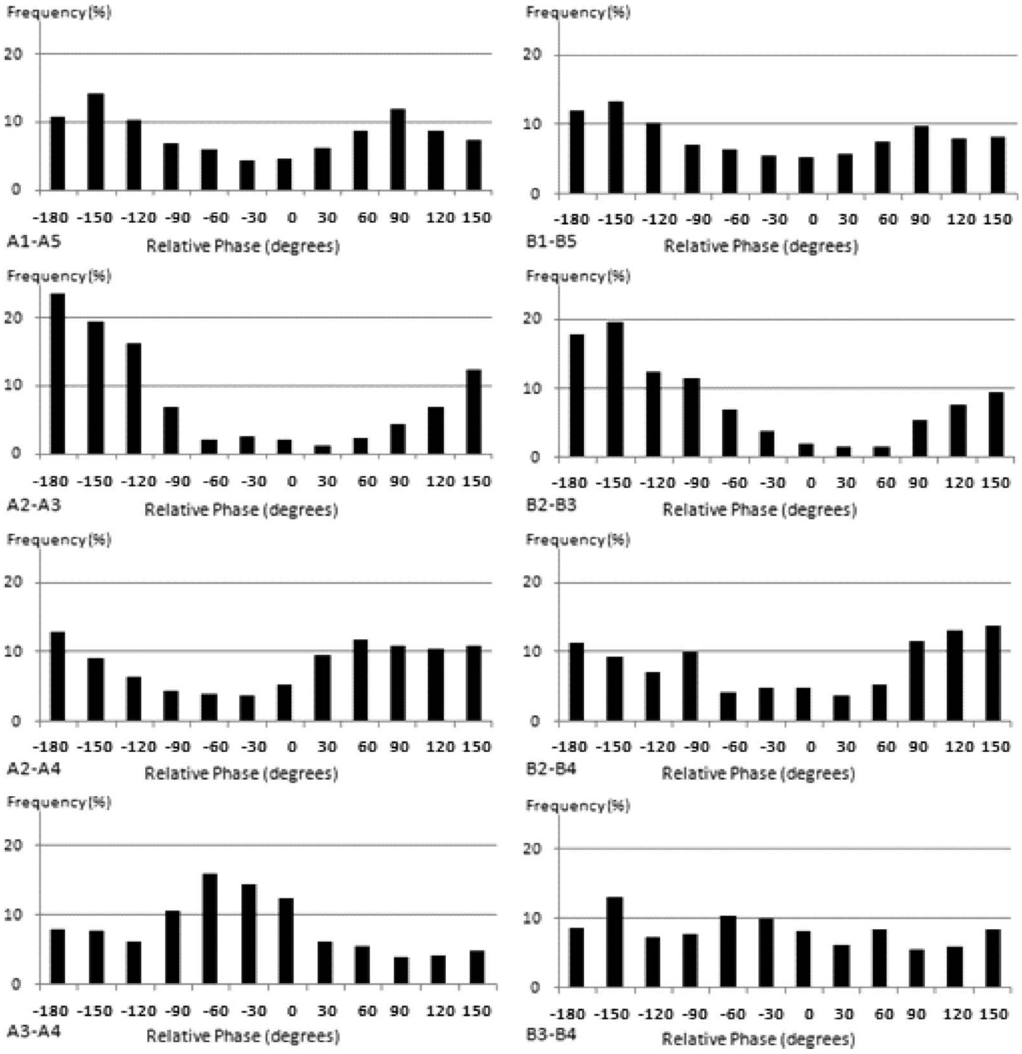

Figure 5. Frequency histograms of the relative-phases of player–player dyads from Team A and Team B using lateral displacement. The identity of the dyad is located in the bottom left-hand corner of each panel.

of Team B was apparently more amenable to change to the game context, with the intra-personal coordination of Team B being produced in response to the behaviours of Team A.

Phase relations, phase stabilities, and phase transitions

In this subsection, we examine stabilities and instabilities in the phase relations as well as phase transitions in a given data sequence. To this end, the earlier forcing of the relative-phase data within −180° and 180° limits was rescinded and the unforced data were analysed using visual inspection. Given the circular (360°) nature of relative phase, values of −270°, 90° and 450° and other 360° multiples all represent the same phase relation, a quarter-phase in this example. In addition, we note that an extra cycle or a missing cycle in one of the two signals under analysis will result in an abrupt relative-phase shift of 360° (i.e. no change in the phase relation). Alternatively, changes in relative phase of longer duration throughout a complete cycle would be the result of phase drift (phase change), indicating different phase relations at different instants. In contrast, transitions of short duration between two different yet otherwise stable phase relations constitute a phase transition.

Figure 6 presents data from select dyads and select data sequences. In the first panel, the player–opponent dyad (A_1-B_1) demonstrates a strong

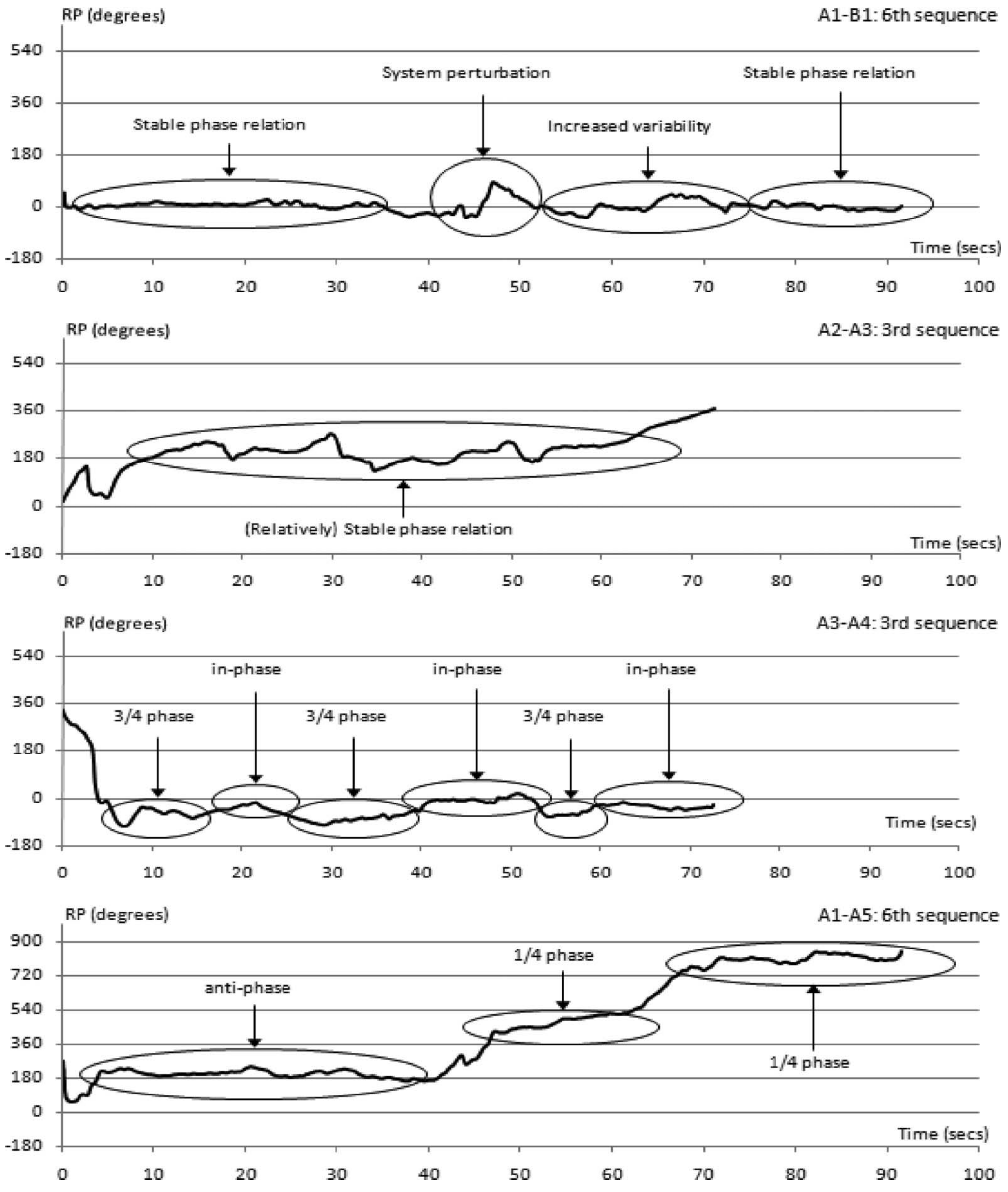

Figure 6. Dynamics of relative-phase for select dyads and select data sequences evidencing stabilities, instabilities as well as transitions in the phase relations. The identity of the dyad and data sequence is located in the top right-hand corner of each panel.

attraction to in-phase that is temporarily disrupted, or perturbed, before the in-phase relation is restored some time thereafter. In terms of system perturbations, it was noted elsewhere that an attacker will often try to free up space from a defender whereas the defender will at the same time look to tie up space of the attacker (McGarry et al., 2002). The brief sojourn of the player–opponent dyad from its typical in-phase pattern might thus be interpreted in similar light. Indeed, further investigation of this particular sequence revealed that the A_1- B_1 phase relation is disrupted because of a "pick", that is, a screen provided for a player by a team-mate on an opponent. In this instance, the pick was performed for A_1 by A_5 on B_1 with the earlier phase relation being reestablished only after B_1 had navigated the pick. The A_1- B_1 relative-phase perturbation is thus attributed to the pick that B_1 experienced.

The second panel in Figure 6 demonstrates a reasonably stable anti-phase relation for the A_2-A_3 dyad. The strength of this attraction is weaker than the in-phase attraction for the A_1-B_1 dyad noted above, as indicated in the increased variability in the anti-phase relation. This increased variability allows for the intermittent although short-lived excursions towards the three-quarter-phase relation (270°). The third panel demonstrates bi-stable phase relations with intermittent switching between in-phase and three-quarter-phase. The fourth panel similarly contains evidence of bi-stable phase relations with intermittent switching, this time from anti-phase to quarter-phase. Taken together, these results of select dyads taken from the collective of players that comprise a basketball game are consistent with some of the expectations of dynamical self-organizing systems (for further details, see Haken, Kelso, & Bunz, 1985). Furthermore, the unique yet recognizable features of the patterned behaviours for each of the dyads presented in Figure 6 demonstrate the useful generality of a dynamical systems approach for describing the varied space–time patterns of dyads that constitute a basketball game.

General discussion

Analysis of the interactions between player dyads allowed for a description of the space–time dynamics of basketball match-play. In the longitudinal direction, a strong attraction to in-phase was reported for all possible dyads but not so for the lateral direction. Instead, attractions to in-phase or anti-phase were observed among most dyads with the player–player dyads tending on balance to demonstrate less pronounced attractions or repulsions to certain relative-phases than the player–opponent dyads. The weaker couplings among team members demonstrated in this research is consistent with the findings of Bourbousson, Poizat, Saury and Seve (in press), who, in a separate investigation using qualitative retrospective interviews, reported the presence of reasonably weak coordination links between players from the same team.

Strategies other than the "man-to-man" marking system used by the two teams reported in this investigation might be predicted to exhibit different phasing relations than those reported here for the various player–player and player–opponent dyads. Nonetheless, phase analysis would be expected to yield similar results in general, with attractions and repulsions to certain phase relations being observed for specific dyads. In other words, while the coordination patterns might vary on account of the different basketball strategies used, among other considerations, the phase relations would nonetheless be predicted to subscribe to similar dynamical descriptions due to the proposed common underpinnings of shared information exchanges among dyads (McGarry et al., 2002).

In summary, analysis of the intra- and inter-couplings of the playing dyads in basketball revealed good evidence for dynamical relations in both the longitudinal and lateral directions. In particular, strongly coupled units among all dyads were observed in the longitudinal direction as well as for particular dyads in the lateral direction. The assertion is that the players that form the dyads attract to and/or repel from each other to produce the unique patterns that characterize their own behaviours and, by extension, a basketball game. Here, we have considered a dyad as a coupling between two players, whereas a dyad might instead be viewed as a coupling between two separate collectives of players, as noted previously in the earlier consideration of layered couplings (i.e. the coupling of couplings). Thus, a basketball game might be investigated at varying levels of analysis using a common system description of dyad interactions, from multiple dyads each comprising two players through to a single dyad comprising two teams. In this article, we report an analysis of game behaviour in basketball from the perspective of interactions among multiple dyads. In the accompanying article, we report an analysis of game behaviour in basketball by examining the interaction in a single dyad, that is, the interaction between two teams.

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