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ORIGINAL ARTICLE

The influence of instructions and body-scaling as constraints on decision-making processes in team sports

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Abstract

Team games conceptualized as dynamical systems engender a view of emergent decision-making behaviour under constraints, although specific effects of instructional and body-scaling constraints have yet to be verified empirically. For this purpose, we studied the effects of task and individual constraints on decision-making processes in basketball. Eleven experienced female players performed 350 trials in 1 vs. 1 sub-phases of basketball in which an attacker tried to perturb the stable state of a dyad formed with a defender (i.e. break the symmetry). In Experiment 1, specific instructions (neutral, risk taking or conservative) were manipulated to observe effects on emergent behaviour of the dyadic system. When attacking players were given conservative instructions, time to cross court mid-line and variability of the attacker's trajectory were significantly greater. In Experiment 2, body-scaling of participants was manipulated by creating dyads with different height relations. When attackers were considerably taller than defenders, there were fewer occurrences of symmetry-breaking. When attackers were considerably shorter than defenders, time to cross court mid-line was significantly shorter than when dyads were composed of athletes of similar height or when attackers were considerably taller than defenders. The data exemplify how interacting task and individual constraints can influence emergent decision-making processes in team ball games.

Keywords: *Cognition, ecological psychology, constraints, emergent behaviour, team sports*

Introduction

Recently, attempts have been made to conceptualize team ball sports as complex, dynamical systems (e.g. Davids, Araújo, & Shuttleworth, 2005; Gréhaigne, Bouthier, & David, 1997; McGarry, Anderson, Wallace, Hughes, & Franks, 2002; Schmidt, O'Brien, & Sysko, 1999). Different sources of complexity can be found in a complex system such as sport competition, including large problem spaces, distributed situatedness, hazards, coupled subsystems, uncertainty, and perturbations (see Araújo, Davids, Bennett, Button, & Chapman, 2004; Vicente, 1999). From this perspective, the characteristics and complexities of each sport should be analysed to understand the different ways in which they constrain the effectiveness of a performer's decisions. In such systems, decision making is considered to emerge from interactions of the different system components, in this case the individual team players (see Araújo, Davids, Sainhas, & Fernandes, 2002; Araújo *et al.*, 2004).

While intrapersonal (i.e. within-person) coordination has been studied extensively using relatively simple between-individual rhythmic tasks (e.g. Schmidt, Carelo, & Turvey, 1990; Schmidt *et al.*, 1999), the 1 vs. 1 sub-phase of team ball games, such as soccer, rugby, and basketball, is a far more complex interpersonal coordination system with an extensive number of constraints on behaviour. In this context, attackers and defenders form closely interacting dyads in which both individuals do not deliberately seek to coordinate actions, since an attacker does not typically seek stable dyadic organization, but attempts to dribble past the marking defender towards the goal or basket (i.e. break the

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symmetry of the system). An important point is that the individuals comprising such systems do not share a common neuronal system, and so emergent coordination processes are uniquely based on the task constraints present in specific environmental contexts (e.g. characteristics specific to individuals involved in each dyad, the instructions from the coach, and the rules of the game).

From this theoretical perspective, information is a physical variable available to constrain behaviour in the environment (Turvey, 1992). To detect such information, the performer needs an intrinsic metric that is specified by dimensions of his or her system. That is, the performer perceives properties of the environment, not in extrinsic units (such as metres, inches, etc.), but in relation to his or her body or body parts dimensions, his or her own action capabilities, and his or her spatial location relative to other important objects, surfaces, and people in the environment (Konczak, Meeuwsen, & Cress, 1992).

For example, the "climbability" of a stair is perceived in relation to an individual's leg length. Warren (1984) found that young adults of a wide range of statures could, by visual inspection alone, determine which in a series of stairs of varied riser heights afforded bipedal climbing and which was the most energy efficient. Warren (1984) showed that the climbability affordance of a particular stair for each individual can be described as a function of the riser height (RH) of a stair and the leg length (LEGL) of the perceiver: $\pi = RH/LEGL$. The perceived critical point at which riser height no longer afforded upright locomotion was stable at a proportional value of 0.88–0.89 of leg length. At this point, climbers were unable to ascend the stair bipedally and a phase transition in behaviour occurred. In climbing, an often observed phase transition is the change from bipedal to quadrupedal locomotion, using hands or knees during a steep ascent. On the other hand, a ratio smaller than the critical ratio specifies bipedal climbability. In the words of Ulrich and colleagues, "Individual *choices* varied but were body-scaled; subjects' *choices* were the same mathematical function of the leg length, regardless of stature" (Ulrich, Thelen, & Niles, 1990, p. 2; our emphasis). Therefore, as van der Kamp and colleagues argued, "body-scaled ratios can be used as a critical determinant of *action choice* – a change beyond the critical ratio value demands a new class of action" (van der Kamp, Savelsbergh, & Davis, 1998, p.352; our emphasis). From this perspective, in these sub-phases, it becomes apparent that individuals do not engage in conscious and rational mental calculations, comparing the current limb–obstacle ratios with an internal representation of a critical ratio, before deciding which action to execute.

In 1 vs. 1 sub-phases of team sports, the specific measurement system that players use for making fundamental decisions, such as when to change direction in approaching a defender, is based on an intrinsic metric (Araújo *et al.*, 2002). Analysis of the coaching literature in basketball (Bain, Hayes, & Quance, 1978) reveals that a candidate control parameter for an attacker–defender system could be the intrinsic metric of the interpersonal distance between an attacker and defender in the 1 vs. 1 sub-phase. The decision to change direction when dribbling might not be made at an absolute value of distance from every defender on every occasion (e.g. 1 m from the defender). Rather, the decision might be made with the intrinsic metric of the specific system formed by each individual attacker and defender in spontaneously formed dyads. The use of an intrinsic metric such as interpersonal distance in each specific dyad signifies that the value of the control parameter might change depending on relevant action-scaled features (e.g. limb sizes) of a specific attacker–defender dyadic system. Sometimes, the relevant distance for changing direction will be greater or smaller in magnitude than an absolute value such as 1 m. On the other hand, an order parameter to describe dyadic system organization might be the median point of the distance of both players from the basket.

Previous research on basketball has suggested that it is an adequate movement model for studying the behaviour of complex neurobiological systems. For example, phase transitions in "attacker–defender–basket systems" (i.e. symmetry-breaking processes) have been observed, with interpersonal distance considered to be a potential control parameter and the distance between the median point of the dyad and the basket as a candidate order parameter (e.g. Araújo *et al.*, 2002; Davids, Button, Araújo, Renshaw, & Hristovski, 2006). Importantly, transitions in the behavioural dynamic patterns were conceptualized as emergent decisions of the system. Results indicated that, at critical values of interpersonal distance, dyadic symmetry was broken, and the system transited from an equilibrium state between attacker and defender to a state of attacker supremacy, when attackers dribbled past defenders with the ball. It was observed that decisions concerning "when" and "how" to break the symmetry of dyadic systems emerged from the interaction of key constraints acting upon players. Despite the important insights provided by these studies, researchers have looked at how instructional and performer constraints might influence these decisions for action.

Several authors (e.g. Davids, Williams, Button, & Court, 2001; Williams & Davids, 1998; Williams, Davids, & Williams, 1999) have underscored the importance of manipulating constraints to optimize the training process in sport. From this perspective, the relative stability of coordination patterns can be affected by different types of constraints, such as the information available and instructions given to each athlete, or even the body-scaled relationships of the athlete with relevant objects, surfaces, and other people in the environment (e.g. Araújo *et al.*, 2004; Kugler, Kelso, & Turvey, 1982; Newell, 1991, 1996). Although poorly understood, it has been argued that some of these key constraints can be manipulated by coaches to facilitate performance and enhance motor learning. Theoretical and empirical analyses have highlighted the key interacting constraints that can influence emergent movement and decision-making behaviours, including intentions (e.g. Davids *et al.*, 2001; Kelso, 1995), instructions and feedback (e.g. Davids, Araújo, Shuttleworth, & Button, 2003; Hodges & Franks, 2002; Newell, 1991; Wulf, Höss, & Prinz, 1998), and body-scaled relationships between actors and among actors and relevant objects and surfaces in dynamic environments (e.g. Konczak *et al.*, 1992; Van der Kamp, Savelsbergh, & Davis, 1998; Warren, 1984). However, while many overviews have provided a sound theoretical rationale for understanding the role of constraints on decision-making behaviour in team sports (e.g. Gréhaigne, *et al.*, 1997; McGarry, *et al.*, 2002; Schmidt *et al.*, 1999), there have been limited empirical efforts to investigate how the manipulation of key constraints affects emergent decision-making processes.

For this reason, we chose to examine how decision-making processes are specifically shaped by task-related instructional constraints and the anthropometric dimensions of practice partners during the 1 v. 1 sub-phase of team games. Two experiments were designed to investigate the effects of key constraints on emergent decision-making processes using a typical 1 vs. 1 sub-phase of the sport of basketball as an experimental model. Previous work has shown that, in this sub-phase, attackers attempt to perturb the stable organizational state of a momentary dyad formed with a marking opponent by dribbling past the defender towards the basket (e.g. Araújo *et al.*, 2004). Defenders try to maintain system stability of the dyad by counteracting any movements towards the basket by attackers with movements of their own to block the path to the basket. If the attacker succeeds in passing the defender, a symmetry-breaking process occurs as the previous stable interpersonal state of coordination in the dyad transits to a new dynamic state; if not, dyadic system symmetry is maintained.

Although earlier work established the existence of such symmetry-breaking processes in 1 vs. 1 sub-phases of team sports, in this paper we report two experiments aimed at analysing the specific influence of two key constraints on emergent decision-making processes in interpersonal systems, identified in previous theoretical overviews and empirical investigations (e.g. Araújo *et al.*, 2004). For this purpose, we manipulated instructional constraints (Experiment 1) and body-scaling of the athletes in individual dyads (to exemplify interactive task and organismic constraints in Experiment 2).

EXPERIMENT 1

Methods

The specific aim of Experiment 1 was to examine the influence of different task instructions (i.e. neutral, risk taking or conservative) on emergent decision making in dyadic behaviour in a typical 1 vs. 1 sub-phase in basketball.

Participants

Ten relatively experienced female basketball players (3 centres, 5 forwards, and 2 guards) aged 15–19 years (mean $\pm s$: 17.5 ± 1.3), who were members of the Portuguese Basketball Federation player development programme, took part in the experiment. Participants provided informed consent and the experiment was conducted according to American Psychological Association (2003) guidelines. Involvement of relatively experienced participants was necessary to ensure that athletes had the requisite skill to satisfy the instructional constraints.

Experimental task

The experiment was undertaken on a basketball court of regulation dimensions. The 1 vs. 1 sub-phase started with a bounce pass to the attacker from the defensive baseline and continued down court to the opposite basket. In each situation, the attacker was instructed to dribble the ball down court and score a basket in accordance with the rules of the game and the specific instructional constraints of the coach. The attacker was required to get past the defender to score or to try and shoot without passing the defender, and no specific instructions were given on exactly how to achieve this goal. The defender was instructed to try to recover possession of the ball and prevent the attacker from scoring, within the rules of the game (see Figure 1).

Athletes were grouped in 10 dyads with similar anthropometric characteristics (for the purposes of this experiment defined as differences in arm span

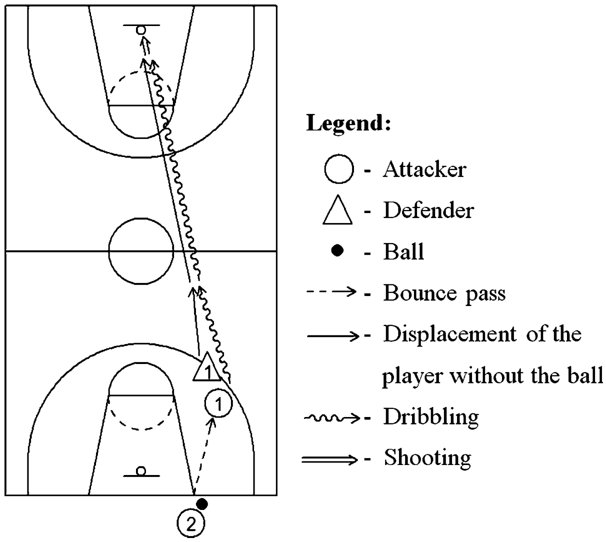

Figure 1. Experimental task. This task purports to simulate a one-on-one game situation. Attacker 1 receives a bounce pass from attacker 2 and proceeds down court to score according to the imposed constraints. Defender 1 tries to recover possession of the ball and prevent the forward from scoring.

no more than 2.9% and differences in height no more than 5.4% for each dyad). The normalized differences in arm span and height in each dyad were calculated by subtracting the anthropometric measure of the shortest athlete from the anthropometric measure of the tallest athlete (i.e. difference in arm span or height of the dyad), and dividing that value by the anthropometric measure of the tallest athlete. Each dyad performed fifteen 1 vs. 1 experimental trials (5 with neutral instructions, 5 with risk-taking instructions, and 5 with conservative instructions), resulting in a total of 150 experimental trials for analysis. This number of experimental trials used in the study was based on previous experimental designs (e.g. Araújo *et al.*, 2002; Davids *et al.*, 2006), which were arrived at to ensure that participants avoided fatigue or attentional deficit effects. The first group of 50 trials was performed with neutral instructions; in the other two groups of 50 trials the athletes were required to react to a verbal cue (i.e. "risk" or "conservative") in a pre-determined random order. Before each trial, verbal instructions were provided by the same member of the experimental team, so that both athletes received the same information about the game scenario. The order of presentation of the risk and conservative instructions was counterbalanced across dyads. After performing ten 1 vs. 1 experimental trials (5 as attackers and 5 as defenders), the athletes rested for 5 min to prevent fatigue from interfering with performance. To create dyads with similar anthropometric characteristics, the athletes were measured following procedures developed by Fragoso and Vieira (2000), using a stadiometer to determine height and a wall and measuring tape to determine arm span.

Independent variables. To analyse the influence of instructional constraints on emergent decision making in dyads, in addition to the basic task instructions to each participant, we manipulated the different information given to them, creating three different experimental conditions in the form of practice vignettes:

1. *Neutral instructions* – we instructed the participants to perform according to the rules of basketball in dribbling towards the basket.
2. *Risk-taking instructions* – we instructed the participants to perform in accordance with a simulated scenario in which a competitive game was going to end in 10 s and their team was losing by 1 point.
3. *Conservative instructions* – we instructed the participants to perform in accordance with a simulated scenario in which a competitive game was going to end in 20 s and their team was winning by 1 point.

Dependent variables. To analyse emergent decision-making behaviour under these different instructional constraints, we plotted the evolution of dyadic behaviour over time, based on the following variables:

i. *Frequency of symmetry-breaking occurrences* – to identify whether an attacker managed to get closer to the basket than a defender, breaking the symmetry of the attacker–defender–basket system. To determine the value of this variable, we analysed the distance of the players to the basket over time (see Figure 2A, B). To establish clarity of symmetry-breaking processes, we measured a variable based on the interpersonal distance within the dyad (i.e. distance between the two players) – the relative interpersonal distance. This variable assumes negative values each time the attacker gets closer to the basket than the defender, since it is weighted by " -1" in this situation. When no symmetry-breaking occurs, plots of interpersonal distance and relative interpersonal distance have the same configuration. On the other hand, when symmetry-breaking occurred, it could be observed clearly in the relative interpersonal distance plot because negative values resulted (see Figure 2C, D). This variable is expressed as a frequency count for instances of symmetry-breaking and no symmetry-breaking.
ii. *Time-to-cross mid-line* – indicating the time (in seconds) that the attacker took to cross the court mid-line.

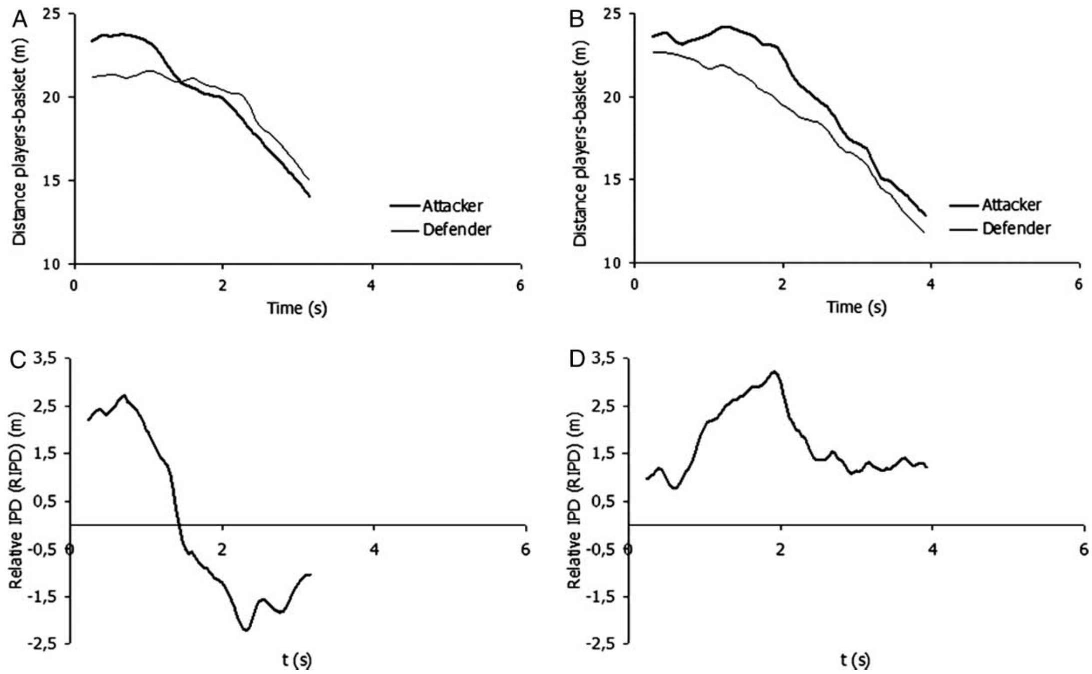

Figure 2. Example of a situation with symmetry-breaking (graphs on the left) and of a situation without symmetry-breaking (graphs on the right). Panels (A) and (B) show the players' distance to the basket throughout time, while panels (C) and (D) show variation in the "relative" interpersonal distance of the same situations. To identify symmetry-breaking, one should look for a crossing of the lines that represent the attacker and the defender on the graph of the players' distance to the basket, or for a negative value of "relative" interpersonal distance.

iii. *Variability of the attacker's trajectory* – indicating the residual standard deviation to a straight line adjusted to the attacker's trajectory (see Figure 3). This straight line was calculated, by non-linear optimization, to minimize the summation of the square of the residuals, which were considered as perpendicular to the straight line. This process differs from traditional linear regression techniques in which the residuals correspond to the distance between the experimental observations and their vertical projections on the straight line. We assumed the ideal trajectory for the attacker to reach the basket in the absence of any impinging constraints, such as the presence of a defender, would be a straight line. The assumption is that deviations from the direct, straight line trajectory to the basket are due to the interaction with a defender present in the dyad. These deviations can be quantified, as a measure of variability, through the residual standard deviation (cf. Öberg, Sandsjö, & Kadefors, 1991).

Procedures

The 1 vs. 1 sub-phases were recorded (AVI, 720 × 576 pixels, 25 Hz) using two video cameras (Sony DCR pc 110E) placed approximately 4.5 m and 5.3 m above floor level in lateral and frontal positions respectively.

The projection on the ground of an approximation of the centre of mass of each athlete (i.e. projection of torso area) was tracked from the moment the ball hit the floor with the initial bounce pass until the moment the ball was recovered by the defender or, in

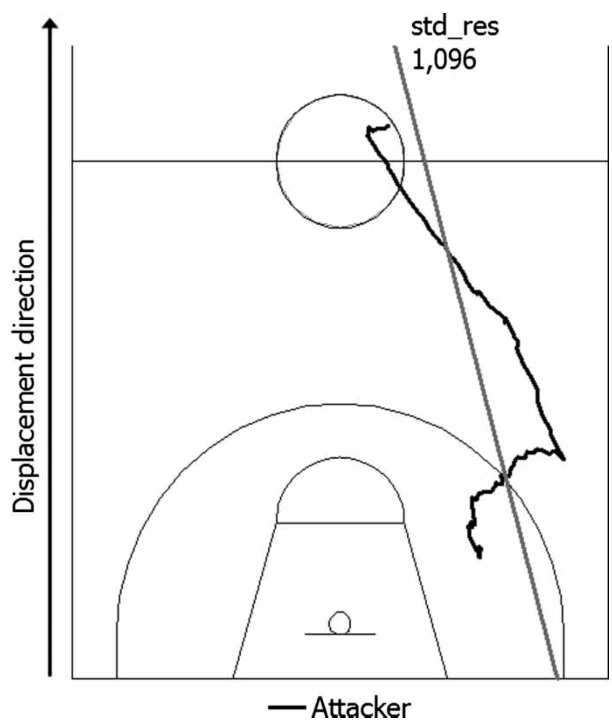

Figure 3. Straight line adjusted to the attacker's trajectory and its residual standard deviation (std_res).

the case of no recovery, until the moment the attacker crossed the mid-line. The tracking procedure, which allowed the calculation of each athlete's trajectory, expressed in real-world coordinates, was based on the video streams of the two cameras as a two-step process.

In a first step, the position of each player within each camera vision field was digitized by using the computer mouse as a pointing device using the software Tacto 7.0 (Fernandes & Caixinha, 2003). This procedure produced two pairs of two-dimensional (2D) coordinates per video frame and player corresponding to the x and y screen coordinates of the player in each frame of the two cameras. The second step consisted in the transformation of the pair of 2D screen coordinates into three-dimensional (3D) real-world coordinates. A set of 21 spatial points, located both outside (up to 2 m apart from the field boundaries) and inside the performance field, with known 3D coordinates and the corresponding pairs of 2D coordinates, was randomly divided into training (14 points) and test (7 points) sets. These sets were fed into STAB (Gouveia, 2004), an MS Excel/VBA based software linked to a feedforward artificial neural network with 4 inputs (x cam1, y cam1, x cam2, y cam2), a 3 neurons hidden layer, and 3 outputs (xrwc, yrwc, zrwc). The artificial neural network was trained until the root mean square error of the test set started to increase.

As in the first step, the position of each player in the video stream was followed with a mouse. Training for the experimental trials digitized by two investigators was undertaken before actual data collection.

Statistical procedures

For all statistical procedures, alpha was set at 0.05. To analyse the data, we employed the Kruskal-Wallis non-parametric test for the nominal variable "symmetry-breaking". We also employed a one-way analysis of variance (ANOVA) for the quantitative variables "time-to-cross mid-line" and "variability of the attacker's trajectory". When equality of variances was not assumed, Dunnet's *C*-test was used as a *post hoc* test (Morgan & Griego, 1998). In addition, effect sizes were calculated.

Results

Calculation of real-world coordinates

To assess inter-individual digitizing accuracy, one of the trials was digitized 27 times in 3 different days by two investigators. An average root mean square error of less than 25×10^{-2} m and a maximum error of 45×10^{-2} m were observed between the calculated trajectories. No significant differences in precision were found between investigators.

Next, the accuracy of the real-world coordinates (RWC) calculation process was assessed by comparison with the artificial neural network (ANN) estimated with the actual RWCs of a set of known points located within the performance field and not previously used in the ANN training process. A maximum bias of 17×10^{-2} m was observed, which corresponds to approximately 1.1% of the field width. Results showed that both the precision and the accuracy of this approach were acceptable for the purpose of tracking the athletes in basketball.

Instructional constraints

The results showed that the nature of instructional constraints on athletes had no effect on the variable "symmetry-breaking" ($H(2) = 1.52$, $P \leq 0.468$).

Analysis of variance revealed that the nature of instructional constraints had significant effects on time-to-cross mid-line ($F_{2,135} = 43.69$, $P \leq 0.001$; $\eta_p^2 = 0.393$) and the variability of the attacker's trajectory ($F_{2,147} = 7.29$, $P \leq 0.001$; $\eta_p^2 = 0.098$).

Post hoc testing revealed the following significant differences. First, the attacker took significantly more time to cross the court mid-line when constrained by conservative task instructions (mean $\pm s$: 5.02 ± 1.23 s) compared with neutral (3.49 ± 0.73 s; $\delta = 1.52$) or risk-taking (3.29 ± 0.88 s; $\delta = 1.63$) instructions. Second, the attacker's trajectory was significantly more variable when constrained by conservative instructions (0.88 ± 0.46 m) compared with neutral (0.66 ± 0.34 m; $\delta = 0.55$) or risk-taking (0.60 ± 0.34 m; $\delta = 0.70$) instructions.

Discussion

The results of Experiment 1 indicate that manipulation of instructional constraints significantly shaped emergent decision making in the 1 vs. 1 sub-phase of the team sport investigated. When participants were required to satisfy conservative instructions, compared with other instructional constraints, the time to cross mid-line and variability of the attacker's trajectory were significantly greater. Moreover, the meaningfulness of this effect (conservative instructions) was predominantly large. Our results indicate how key instructional constraints can significantly modify decision-making processes from moment to moment during team ball sports and how the type of instruction given to an athlete can influence intentionality (Araújo *et al.*, 2004; Davids *et al.*, 2006). When confronted with a simulation where the main tactical goal was to avoid losing the ball, decision-making strategies were modified to satisfy immediate task constraints, resulting, for example, in increased

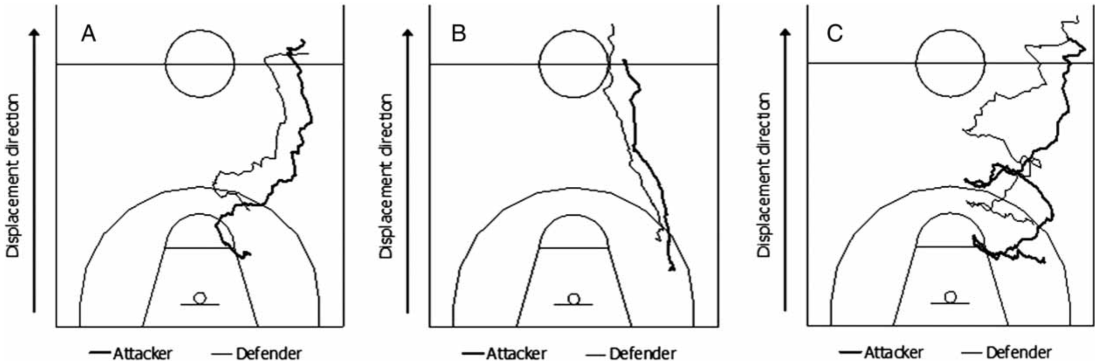

Figure 4. Trajectories of the players in three different instructional scenarios: neutral instruction (A), risk-taking instruction (B), and conservative instruction (C).

variability in movement trajectory (e.g. see Figure 4C).

These results demonstrate that, due to the lack of contextual information, the selection of a goal path cannot be prepared too far in advance and in great detail by athletes, but emerges from the imposed, interacting constraints, reflecting the dynamics of team ball sports as a complex system (cf. Araújo et al., 2004). The lack of significant differences between the neutral and risk-taking instructions may be explained by the characteristic tempo of basketball, a dynamical game where decision making occurs under severe time constraints (Jordane & Martín, 1999). In this respect, the typical characteristic dynamics of basketball are closer to a risk-taking scenario than to a conservative scenario, and this fact is probably even more obvious in expert athletes. Without a more specific game scenario to work with (i.e. neutral instructions), participants focused on the most obvious task goal in the 1 vs. 1 sub-phase of the team game, that is to outscore the opposition. From a dynamical systems perspective, it was expected that risk-taking instructions would encourage greater movement variability by attackers to try to break the dyad symmetry, since the existence of critical fluctuations usually precedes phase transitions. However, that movement variability might have not been noticeable, since in the present study the instructional scenarios did not influence the frequency of symmetry-breaking occurrences, probably due to the area of the court chosen for analysis. In this respect, participants might have been influenced by the spatial location of the 1 vs. 1 sub-phase. Indeed, further research is needed to ascertain whether this sensibility to initial conditions of the experiment might have had a greater impact – that is, creating more fluctuations and different types of symmetries in dyads (e.g. direct, inverse) – if it had occurred nearer the basket (Araújo *et al.*, 2002, 2004; Davids *et al.*, 2006). Even in the risk-taking scenario, the priority of the attacker was probably to move down court quickly to score without risking loss of ball possession. So, the decision of trying to break the symmetry was probably postponed to an area closer to the basket. On the other hand, the movement variability shown in the conservative condition is probably a strategy to "run" down time (i.e. variability in the trajectory) and not the same type of variability (i.e. fluctuations in change in direction) that usually precedes phase transition in the dyadic system.

In this game scenario, the instructional constraints influenced movements between the two players in a way that appeared to mirror what Schmidt *et al.* (1999, p. 574) defined as "a linkage of both movements and minds". Indeed, we observed that different kinds of coordination emerged according to the task constraints. These dynamic patterns were highly context sensitive, as is predicted by dynamical systems theory. Indeed, Kelso and Engström (2006) argued that transitions among stable states occur as a result of dynamic instability. Dynamic instability or metastability in complex systems provides a universal decision-making process for switching between and selection among polarized states. Thus, if there are better ways to fit the circumstances and context of a given coordination pattern, fluctuations will help the system discover and explore them. This is not a switch *per se*, but a qualitative change that arises due to the intrinsic non-linearity of the pattern dynamics. These ideas have clear implications for interpreting decision making and action in complex, dyadic systems in team sports, with variability viewed as an important aspect of each dyadic component attempting to improve the fit with the environment through adaptive behaviours. As predicted, the findings of Experiment 1 have important implications for the way that practitioners manipulate instructional constraints of practice settings to influence emergent decision-making processes.

EXPERIMENT 2

Methods

The aim of Experiment 2 was to determine whether different anthropometric relationships between specific pairs of attackers and defenders in dyads (i.e., differences in total heights between the players) provide an external constraint on the decision-making process in 1 vs. 1 sub-phases of basketball.

Participants

Eleven relatively experienced female basketball players (3 centres, 5 forwards, and 3 guards) aged 14–19 years (17.2 ± 1.5), and height ranging between 1.65 and 2.00 m (1.76 ± 9.50), took part in the experiment. The participants were the same as in Experiment 1, plus one individual who was not included in the previous experiment due a discrepancy between her height and the rest of the players. Participants provided informed consent and the experiment was conducted according to American Psychological Association (2003) guidelines.

Procedures

Procedures were the same as in Experiment 1, except for the independent variables and the statistical procedures selected. In this experiment, in accordance with the results of Experiment 1, neutral instructions were given to the athletes in the 1 vs. 1 sub-phases ($N = 250$). The use of neutral instructions was designed to negate the effects of differing intentions of participants and to limit any effects of differing positional roles of each player on dribbling performance. To analyse the specific influence of body-scaling on decision making, we manipulated the anthropometric relationships of the athletes, creating specific dyads with different height relationships. To achieve these distinct relationships, we subdivided the sample according to anthropometric characteristics (i.e. three groups of dyads organized by minimal differences, moderate differences, and marked differences between height dimensions of each individual). We created five groups for height (H) as follows:

- 1H – dyad with similar heights (attacker–defender differences between 0.2% and 2.7%);
- 2H – attacker moderately taller (between 3% and 5.4%);
- 3H-attacker moderately shorter (between 3% and 5.4%);
- 4H – attacker considerably taller (between 6.7% and 15.4%);
- 5H – attacker considerably shorter (between 6.7% and 15.4%).

Statistical procedures

We set alpha at 0.05 for all statistical procedures. A Kruskal-Wallis non-parametric test was used for the variable "symmetry-breaking", as in Experiment 1. However, when significant differences were obtained for this variable among the multiple groups, we used Siegel and Castellan's (1988) correction method of multiple comparisons between treatments as a *post hoc* test.

We employed a one-way ANOVA for the quantitative variables "time to cross mid-line" and "variability of the attacker's trajectory". There was equality of variances between the groups; and we implemented a Bonferroni test to reduce the probability of Type 1 errors. In addition, effect sizes were calculated.

Results

Height constraints

Manipulation of the height of players in dyads revealed significant differences for the existence of symmetry-breaking ($H(4) = 14.54$, $P \leq 0.006$).

Post hoc testing revealed the following significant differences. First, in dyads of similar heights (i.e. group 1H), there were more instances of symmetry-breaking (mean rank = 133.22) than in dyads where attackers were considerably taller than defenders (i.e. group 4H) (mean rank = 95.38). Second, in dyads where attackers were moderately shorter than defenders (i.e. group 3H), there were more instances of symmetry-breaking (mean rank = 132.88) than in dyads where attackers were considerably taller than defenders (i.e. group 4H) (mean rank = 95.38). Third, in dyads where attackers were considerably shorter than defenders (i.e. group 5H), there were more instances of symmetry-breaking (mean rank = 136.00) than in dyads where attackers were considerably taller than defenders (i.e. group 4H) (mean rank = 95.38).

Analysis of variance also revealed significant differences in the time to cross the court mid-line ($F_{4,221} = 4.03$, $P \leq 0.004$) ($\eta_p^2 = 0.068$), but no significant effect for variability of the attacker's trajectory.

Post hoc testing revealed the following. First, the attacker took significantly less time to cross mid-line when she was considerably shorter than the defender (i.e. group 5H: mean = 3.00 ± 0.89 s) than when members of the dyad were of similar height (i.e. group 1H: mean = 3.57 ± 0.89 s) ($P \leq 0.019$; $\delta = 0.64$). Second, the attacker took significantly less time to cross the court mid-line when she was considerably shorter than the defender (i.e. group 5H: mean = 3.00 ± 0.89 s) than when she was considerably taller than the defender (i.e. group 4H: mean $= 3.81 \pm 0.98$ s) ($P \leq .003$; $\delta = 0.87$).

Discussion

In Experiment 2, when height was manipulated, it can be concluded that there were significantly fewer symmetry-breaking occurrences when attackers were considerably taller than defenders compared with all other dyadic combinations except for dyads in which attackers were moderately taller than defenders. These results imply that being considerably taller than the defender constitutes, when dribbling in 1 vs. 1 sub-phases of basketball, a disadvantage for attackers.

However, careful perusal of the data showed how height differences between players led to subtle interactions between participants as they attempted to maintain and incur system stability. In this respect, the data exemplified how body-scaling can be construed as a key constraint on decision-making processes during 1 vs. 1 sub-phases of team sports (Araújo *et al.*, 2004; Davids *et al.*, 2006). When differences in height between players in the dyad were moderate, system dynamics were not greatly affected, with few significant effects on key variables.

Analysis of the data also revealed that when the attacker was considerably shorter than the defender, time to cross the mid-line was significantly reduced compared with dyads of similar heights and when the attacker was considerably taller than the defender. The meaningfulness of this effect (height difference) was medium to large. These results support the notion of an advantage of the attacker being shorter than the defender under these specific experimental task constraints. When the attacker was considerably shorter than the defender, the reduced time to cross mid-line might have constituted a strategy by the defender of maintaining system stability over time. This approach by the defender, of moving back and giving some room to the attacker, actually enhances system stability by delaying the 1 vs. 1 confrontation to an area closer to the basket. When attackers were considerably taller than defenders, it is possible that they tried to manipulate interpersonal distance by intensifying pressure only in the area of the court that might give them a greater tactical advantage (i.e. closer to the basket). When nearer to the basket, the taller defenders used their height advantage to limit shooting opportunities. This interpretation of the data might also explain why time to cross the court mid-line was significantly reduced when attackers were considerably shorter than defenders, compared with dyads of similar heights. It is possible that in dyads of similar heights, defenders attempted to exert more pressure from the beginning of the 1 vs. 1 sub-phase; however, when attackers were considerably shorter than defenders, the latter might have maintained system stability by postponing their confrontation.

General discussion

The experiments reported in this paper revealed the importance of constraints on emergent decision making in attacker–defender dyads, since both the manipulation of task and individual constraints were shown to clearly influence system dynamics. There was some evidence to interpret decision making as an emergent process under differing task constraints. In these experiments, we analysed instructional and body-scaling constraints. Instructional constraints clearly and meaningfully shaped decision-making strategies, resulting in increased movement trajectory variability and a greater time to cross mid-line when athletes were given conservative instructions. On the other hand, height constraints influenced the number of symmetry-breaking occurrences and time to cross mid-line mainly in the group where attackers were considerably taller than defenders.

Our analysis of 1 vs. 1 sub-phases of team sports revealed that specific instructional constraints probably interacted with the intentionality of the players, causing obvious changes to their behaviour depending on the game scenario (see Davids *et al.*, 2001). The results also suggest that anthropometric constraints probably interacted with the relative positioning of each player during the game, causing the system to exhibit particular types of behaviour when the attacker was considerably taller than the defender. This difference in system behaviour was characterized by an increase in time to cross the court mid-line, and by the existence of fewer symmetry-breaking occurrences, compared with most other conditions.

The finding that the manipulation of task constraints, such as instructions to the athletes, had significant repercussions on system dynamics emphasizes the role of the coach, who can channel the search activities of athletes by creating practice conditions that facilitate the discovery and exploitation of different solutions for satisfying task constraints. Highly prescriptive and detailed instructions have been considered as detrimental to the search process and the exploration of the dynamics of the perceptual-motor workspace, limiting the performer's decision making and actions. On the other hand, allowing random searching would be time-consuming and possibly unsafe, and could lead to losses of confidence and motivation (Williams *et al.*, 1999). In this investigation, an instruction was issued that created different scenarios (i.e. neutral, risk-taking or conservative instruction), and it seems to have provided athletes with the opportunity to discover and exploit specific solutions for each situation and to achieve adequate task solutions, depending on the task constraints imposed. Successful coaches should be able to achieve a balance between encouraging persistence and change, allowing the learner to probe various states of system stability, identifying the dynamic characteristics of the system, and discovering multiple task solutions (Araújo *et al.*, 2004; Davids *et al.*, 2001).

That a greater height of the attacker, relative to the defender, seemed to be a disadvantage in the 1 vs. 1 sub-phase, provides a practical contribution of some relevance to team sports. In the initial learning stages, it is important to carefully consider the pairing of partners in dyads so that the player with the ball can achieve some success (Barreto, 2002). Typically, many coaches use the technique of passive defending to achieve this objective. However, these results suggest that to ensure an effective pairing during practice of the 1 vs. 1 sub-phase, the body-scaled characteristics of the athletes are also fundamental. In the initial learning stages, a greater height of the attacker might not constitute a disadvantage in a dyad, compared with practice constraints for more experienced players. It is important that early in learning, all athletes have the opportunity to practise against partners varying in limb segment dimensions. Later in learning, creating situations with major difficulties for more experienced players (e.g. forming dyads where the attacker is considerably taller than the defender) might lead to the discovery of alternative coordination solutions for athletes to enhance their skills (see Araújo *et al.*, 2004). This idea requires empirical verification.

It is also important to note that while investigating the 1 vs. 1 sub-phase of team sports is insightful, the emergence of decision making in game-like situations arises out of the interaction with other players and opponents in the game. Further research is needed in other sub-phases of team sports (e.g. 2 vs. 2 or 3 vs. 2) to understand how dynamics of interpersonal interactions can shape significant elements of contextual decision making in basketball (e.g. choosing whether/when to pass and creating space for team-mates to exploit).

In future research, other factors might be analysed as powerful constraints on emergent decision-making behaviour, including: (i) the location of the court where the 1 vs. 1 sub-phase occurs, relative to the basket (i.e. closer or farther away from the basket, in a central or lateral corridor); (ii) the positional role of each player in the team (i.e. point guard, shooting guard, small forward, power forward, and centre); (iii) previous knowledge that the attacker and defender have of each other (i.e. understanding of relative strengths and weaknesses of the behaviour of specific opponents); and (iv) the skill of the athletes (i.e. beginners or experts). These are constraints considered by coaches to be influential in the decision-making process in basketball, and applied research is needed to examine coaches' intuitions.

In conclusion, the results of these experiments support the value of studying sub-phases of team sports with concepts and tools from dynamical systems theory. They raise interesting questions for future research that might help clarify understanding of decision making in team ball sports as an emergent process. A better knowledge of the constraints that shape decision making might be important not only for guiding beginner athletes, but also to help more experienced athletes to discover and explore novel coordination solutions.

References

American Psychological Association (2003). *Ethical principles of psychologists and code of conduct* (accessed 20 July 2003 at: http://www.apa.org/ethics/code2002.html).

Araújo, D., Davids, K., Bennett, S., Button, C., & Chapman, G. (2004). Emergence of sport skills under constraints. In A. M. Williams, & N. J. Hodges (Eds.), *Skill acquisition in sport: Research, theory and practice* (pp. 409–433). London: Routledge, Taylor & Francis.

Araújo, D., Davids, K., Sainhas, J., & Fernandes, O. (2002). Emergent decision-making in sport: A constraints-led approach. In L. P. B. Toussaint (Ed.), *International Congress "Movement, Attention and Perception"* (p. 77). Poitiers: Université de Poitiers.

Bain, B., Hayes, D., & Quance, A. (1978). *Coaching certification manual – Level two.* Canada: J. Seaman, Basketball Canada.

Barreto, H. (2002). Orientações para a aprendizagem da habilidade de discriminar distâncias. Situação crítica: defensor do atacante com bola. In S. Godoy, & M. García (Eds.), *Novos Horizontes para o Treino do Basquetebol* (pp. 137–153). Cruz Quebrada: FMH Edições.

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of dynamical systems theory to football. In T. Reilly, J. Cabri, & D. Araújo (Eds.), *Science and football V* (pp. 547–560). London: Routledge.

Davids, K., Araújo, D., Shuttleworth, R., & Button, C. (2003). Acquiring skill in sport: A constraints-led perspective. *International Journal of Computer Science in Sport*, *2*, 31–39.

Davids, K., Button, C., Araújo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human motor systems. *Adaptive Behaviour*, *14*, 73–95.

Davids, K., Williams, M., Button, C., & Court, M. (2001). An integrative modelling approach to the study of intentional movement behaviour. In R. N. Singer, H. Hausenblas, & C. Janelle (Eds.), *Handbook of sport psychology* (pp. 144–173). New York: Wiley.

Fernandes, O., & Caixinha, P. (2003). A new method in time–motion analysis in soccer training and competition. In *Book of Abstracts – Science and Football, 5th World Congress* (pp. 270–271). Lisbon: Editorial Gymnos.

Fragoso, I., & Vieira, M. (2000). *Morfologia e Crescimento – Curso prático.* Cruz Quebrada: FMH Edições.

Gouveia, L. F. (2004). *STAB (MS Excel template and VBA code to perform 2D coordinates calculation and stability analysis of athlete dyads in basketball)* (available online at: http://www.ff.ul.pt/~lgouveia/software).

Gréhaigne, J. F., Bouthier, D., & David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences*, *15*, 137–149.

Hodges, N., & Franks, I. (2002). Modelling coaching practice: The role of instruction and demonstration. *Journal of Sports Sciences*, *20*, 793–811.

Jordane, F., & Martín, J. (1999). *Baloncesto. Bases para el alto rendimiento.* Barcelona: Editorial Hispano Europea.

Kelso, J. S. (1995). *Dynamic patterns: The self-organization of brain and behaviour*. Cambridge, MA: MIT Press.

Kelso, J., & Engström, D. (2006). *The complementary nature*. Cambridge, MA: MIT Press.

Konczack, J., Meeuwsen, H., & Cress, M. (1992). Changing affordances in stair climbing: The perception of maximum climbability in young and older adults. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 691–697.

Kugler, P., Kelso, J. S., & Turvey, M. (1982). On the control and co-ordination of naturally developing systems. In J. S. Kelso, & J. Clark (Eds.), *The development of movement control and co-ordination* (pp. 5–78). New York: Wiley.

McGarry, T., Anderson, D., Wallace, S., Hughes, M., & Franks, I. (2002). Sport competition as a dynamical self-organizing system. *Journal of Sports Sciences*, *20*, 771–781.

Morgan, G., & Griego, O. (1998). *Easy use and interpretation of SPSS for Windows: Answering research questions with statistics*. Mahwah, NJ: Lawrence Erlbaum Associates.

Newell, K. M. (1991). Motor skill acquisition. *Annual Reviews of Psychology*, *42*, 213–237.

Newell, K. M. (1996). Change in movement and skill: Learning, retention, and transfer. In M. L. Latash, & M. T. Turvey (Eds.), *Dexterity and its development* (pp. 393–430). Mahwah, NJ: Lawrence Erlbaum Associates.

Öberg, T., Sandjö, L., & Kadefors, R. (1991). Variability of the EMG mean power frequency: A study on the trapezius muscle. *Journal of Electromyography and Kinesiology*, *1*, 237–243.

Schmidt, R. C., Carelo, C., & Turvey, M. T. (1990). Phase transitions and critical fluctuations in the visual coordination of rhythmic movements between people. *Journal of Experimental Psychology: Human Perception and Performance*, *16*, 227–247.

Schmidt, R. C., O'Brien, B., & Sysko, R. (1999). Self-organization of between-persons cooperative tasks and possible applications to sport. *International Journal of Sport Psychology*, *30*, 558–579.

Siegel, S., & Castellan, N. J. (1988). *Nonparametric statistics for the behavioural sciences*. New York: McGraw-Hill.

Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. *Ecological Psychology*, *4*, 173–187.

Ulrich, B. D., Thelen, E., & Niles, D. (1990). Perceptual determinants of action: stair-climbing choices of infants and toddlers. In J. Clark, & J. Humphrey (Eds.), *Advances in motor development research III* (pp. 1–15). New York: AMS Press.

Van der Kamp, J., Savelsbergh, G. J. P., & Davis, W. E. (1998). Body-scaled ratio as a control parameter for prehension in 5- to 9-year-old children. *Developmental Psychobiology*, *33*, 351–361.

Vicente, K. (1999). *Cognitive work analysis*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Warren, W. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, *10*, 683–703.

Williams, A. M., & Davids, K. (1998). Visual search strategy, selective attention, and expertise in soccer. *Research Quarterly for Exercise and Sport*, *69*, 111–128.

Williams, A. M., Davids, K., & Williams, J. G. (1999). *Visual perception and action in sport*. London: E & FN Spon.

Wulf, G., Höss, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behaviour*, *30*, 169–179.