Angular relationships regulate coordination tendencies of performers in attacker–defender dyads in team sports

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Abstract

This study examined the continuous interpersonal interactions of performers in dyadic systems in team sports, as a function of changing information constraints. As a task vehicle, we investigated how attackers attained success in 1v1 sub-phases of basketball by exploring angular relations with immediate opponents and the basket. We hypothesized that angular relations would convey information for the attackers to dribble past defenders. Four basketball players performed as an attacker and defender in 1v1 sub-phases of basketball, in which the co-positioning and orientation of participants relative to the basket was manipulated. After video recording performance behaviors, we digitized participant movement displacement trajectories and categorized trials as successful or unsuccessful (from the attackers’ viewpoint). Results revealed that, to successfully dribble past a defender, attackers tended to explore the left hand side of the space by defenders by increasing their angular velocity and decreasing their angular variability, especially in the center of the court. Interpersonal interactions and goal-achievement in attacker–defender dyads appear to have been constrained by the angular relations sustained.

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1. Introduction

Research on collective social systems has shown that patterns of behaviors of individual members remain continuously co-dependent over space and time (Araújo, Davids, Bennett, Button, & Chapman, 2004; Davids, Button, Araújo, Renshaw, & Hristovski, 2006; Schmidt & Richardson, 2008). For example, Schmidt and O’Brien (1997) used a visual wrist-pendulum task to investigate unintended interpersonal coordination in dyads. They found that, when visual information from one participant was available, particular coordination modes were more frequently observed than others, suggesting how the interpersonal interactions between individuals in a social collective were informationally coupled.

In team sport collectives, competing individuals continuously interact to achieve specific performance goals such as when a ball carrier strives to pass a ball to a teammate before a defender moves into position to intercept the ball (Travassos, Araújo, Davids, et al., 2012). An ecological dynamics approach is a viable theoretical framework which seeks to understand and explain how evolving constraints influence transitions in coordination tendencies between individuals in collective systems like team sports (underpinning actions and decision-making behaviors) (Araújo & Davids, 2009). According to this rationale, an individual’s performance behaviors are continuously dependent on use of specifying information within particular performance environments (Araújo, Davids, & Hristovski, 2006).

A major task for movement scientists is to seek to develop understanding of the effects of key information constraints on the continuous interpersonal interactions of individuals in such social systems (Vilar, Araújo, Davids, & Button, 2012). For example, research has begun to identify relevant informational constraints that support performance behaviors of attackers and defenders in 1v1 sub-phases of team games. In empirical work on 1v1 sub-phases, values of interpersonal distance in basketball (i.e., distance between an attacker and immediate defender) (Cordovil et al., 2009) and relative velocity in association football (i.e., velocity differential between attacker and defender movement displacements) (Duarte et al., 2010), have been shown to influence performance behaviors of attackers dribble past defenders and approach the scoring target. In fact, the relative positioning of performers to a scoring target has been identified in previous research as a critical feature for studying collective and dyadic system dynamics in team sports (Araújo et al., 2004; Travassos, Araújo, Duarte, & McGarry, 2012). To exemplify, a recent study in basketball showed that interpersonal coordination tendencies (i.e., dynamics of the relationship between an attacker and defender) were shaped by manipulation of the relative position of attacker–defender dyads to the basket, suggesting that attackers preferred to move past the defender on the left (Esteves et al., 2012). In futsal (a five-versus-five indoor football game), it was reported that the angular relations between an attacker, defender and the goal constrained success in shooting at goal by the attacker (Vilar et al., 2012). Another investigation of 1v1 sub-phases of rugby union examined running angles of an attacker and a defender in relation to the try line (Passos et al., 2009). However, the method of computing the dependent variable in that study did not enable investigators to differentiate between a leftward or rightward move by the attacker to pass the defender (i.e., an attacker positioned to the left or right of the defender returned a value of 0°, meaning that the attacker–defender vector was parallel to the try line).

These studies highlighted the importance of team games players engaging in exploratory actions to create information for action (Whitagen, de Poel, Araújo, & Pepping, 2012). In ecological psychology, Gibson (1966) conceived a perceiver as an active individual seeking to detect invariant patterns in the surrounding ambient energy arrays, acting as information to regulate functional behaviors. The ongoing process of exploration throughout a specific perceptual motor performance workspace

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implies an actor searching for, and mapping, perceptual invariants to an action system (Kugler & Turvey, 1987). The investigation of qualitative changes in movement dynamics might lead to useful knowledge regarding the benefits of adaptive, exploratory behaviors in humans (Newell, 1991).

In the study of team sports performance, these exploratory behaviors have been exemplified in 1v1 dyads when an attacker attempts to manage interpersonal distance values and create a velocity differential to move past an immediate opponent (e.g., Duarte et al., 2010). Other work has shown how attackers seek to misalign their positioning with an immediate defender to shoot at a target (e.g., Vilar et al., 2012). However, no explanatory data exist on how attackers attempt to break the stability of their alignment with opponents to approach a scoring target and convert a shot, according to the positioning of the dyad relative to a scoring target.

In this study we sought to extend current knowledge on the exploratory behaviors of an attacker in a 1v1 dyadic system attempting to break stable alignments with an immediate opponent to create a scoring opportunity in the team sport of basketball. We attempted to achieve our aim by considering the co-positioning of the attacker and defender relative to the location of the basket, revealing their angular relations.

In line with previous findings, we hypothesized that, to successfully dribble past a defender, an attacker would tend to explore the left side of the dyad by generating a large angular velocity, as it would permit a rapid break in the stable alignment with an opponent, in order to approach the scoring target. Results from this study are expected to provide insights on how exploratory actions in sport are constrained by evolving information constraints emanating from continuous angular relationships between competing performers and a scoring target.

2. Methods

Four (N = 4) male, right-handed, intermediate level basketball players, aged 15 years, with an average of 10 years of basketball practice (SD = .82), participated in the experiment. For each participant parental written informed consent was obtained. We chose athletes at this developmental stage as participants to study because we did not want the lack of skill of complete novices to confound our data.

The experimental task consisted of a 1v1 sub-phase played on a basketball half-court. Each attacker formed a dyad with 3 defenders, who took turns defending. The attacker was instructed to shoot at the basket after attempting to dribble past the marking defender within the performance area. The marking defender aimed to prevent the attacker from dribbling past him and shooting within the same area. Second and third defenders were instructed to maintain a prescribed static position, in order to constrain the attacker from dribbling outside the performance area.

A basketball half-court was divided into 9 different performance areas corresponding to a specific angular positioning to the basket: from p1 to p9 each with an increment of 20° (Fig. 1, left). The 1v1 sub-phase began with an attacker positioned 1.15 m away from the 3-point line, and with a marking defender 0.85 m in front (aligned with the basket). The 3-point line limited backward movements of the marking defender in the direction of the basket (Fig. 1, right).

A bounce-pass from the marking defender to the attacker signaled the beginning of the 1v1 sub-phase that ended when the ball was either intercepted by the defender or shot by the attacker. Each participant performed three trials in each performance area, for a total of 27 trials. The overall relative positions were presented to the participants in two consecutive sequences, comprising a total of 162 trials. First, increasing sequence of presentation (p1–p9) and then decreasing sequence (p9–p1).

Our criterion for considering sample size was based on Brunswik’s (1956) conceptualization of representative experimental design. More than simply referring to the number of participants involved in a study, Brunswik (1956) argued that sampling should consider the degree of generalization of experimental task constraints to performance settings. From this perspective, sampling in experimental research needs to also consider the situations and behaviors in a performance environment for the purpose of study, and not just the individuals per se (Araújo, Davids, & Passos, 2007). This proposition is intimately related to the richness of ecological constraints inherent to many sports performance contexts used as relevant experimental task vehicles for studying human behaviors. As in
the present study (e.g., Araújo et al., 2006; Travassos, Araújo, McGarry, & Vilar, 2011), utilization of these performance constraints may help to clarify how functional processes operate in adaptive and exploratory behaviors, such as perception and actions (Davids et al., 2006).

A digital video camera placed at an angle of 45° to the mid-court line, in a superior plane, recorded participant performance at 25 Hz. Video footage of performance was trimmed to consider the beginning and end of each trial, and we digitized participant movement displacement trajectories with TACTO software 7.0 (Duarte et al., 2010; Fernandes, Folgado, Duarte, & Malta, 2010). This procedure consisted of following the vertical projection of the working point of the attacker and marking defender on the floor, in each film clip, with a computer mouse. The recorded virtual coordinates were transformed into real coordinates using the direct linear transformation method (2D-DLT) and subjected to a 6 Hz low pass filter (Winter, 2005). Intra-rater reliability for the digitization, over four consecutive days, of an exemplar trial of participant displacement movement trajectory was $\alpha = .99$, $p < .01$.

All trials were categorized as successful or unsuccessful (from the attackers’ point of view) according to the performance outcomes in the 1v1 sub-phase. First, an experienced basketball coach (with 18 years of officiating experience) visual inspected video images of participants’ performance to identify fouls (i.e., violations to basketball rules) and ball interceptions by the defender to classify unsuccessful trials. We also examined whether the movement displacement trajectories of the attacker proceeded outside the lateral limits of each performance area to classify them as unsuccessful trials. For that purpose, the values of the distance of the attackers’ position (point-by-point in the time series) to the lateral limits of the performance area were computed. A total of 44.4% of trials were categorized as successful for the attacker and 55.6% as unsuccessful. The proportion of successful trials, according to the different relative positions to the basket ($p1$–$p9$), were as follows: 47.1% ($p1$); 66.7% ($p2$); 55.6% ($p3$); 44.4% ($p4$); 44.4% ($p5$); 38.9% ($p6$); 50% ($p7$); 27.8% ($p8$) and 44.4% ($p9$). Intra and inter-reliability for the categorization process, completed with the experiential knowledge of an expert basketball referee (12 years experience), was respectively $\alpha = .85$, $p < .01$ and $\alpha = .81$, $p < .01$.

To capture angular relations between the attacker and defender in relation to the basket we computed the attacker–defender-basket angle (ADB), assigned as $\beta$. Initially, we calculated the angle $\theta$ formed by the defender–attacker (DA) vector, with respect to the MC vector (orthogonal to the lateral limits of the performance area). Then, we performed a rotation of $-90^\circ$, clockwise, of angle $\theta$ so that the referential of $0^\circ$ for the ADB ($\beta$) would be coincident with the BM vector (orthogonal to the end line of the court) (Fig. 2).

Fig. 1. Half-court of basketball with 9 different areas correspondent to different relative positions to the basket where the 1v1 situation should take place: $p1$–$p9$ (left). Starting positions of attacker (1), first defender (2), second defender (3) and third defender (4) in the 1v1 sub-phase correspondent to $80–100^\circ$ ($p5$) of relative position to the basket (right).
This procedure allowed us to identify when the attacker: (i) was facing the defender in front of the basket (0°); (ii) attempted to dribble past the defender on the left side (90°); and (iii), attempted to dribble past the defender on the right side (−90°). We computed the angular velocity of ADB (rad s⁻¹) by considering the variation of angular displacement as a function of time (0.04 s). We also evaluated the dynamics of the ADB time series by using a measure of approximate entropy (ApEn), which provided a quantification of its structure of variability, (i.e., the probability of a pattern being repeated over time) (Stergiou, Buzzi, Kurz, & Heidel, 2004). Interpersonal distance (m) values were computed according to the Cartesian distance between the positions of an attacker and defender on court.

Our dependent variables (ADB, angular velocity of ADB and ApEn of ADB) were computed in a time series from the moment when the attacker received the ball from the marking defender (i.e., beginning of the sub-phase), to the moment when the attacker shot at the basket, reached the second and third defenders or lost ball possession (i.e., at 4.6 m from the basket). For statistical purposes all variables were normalized with respect to time by taking the shortest trial as a reference, which was further divided into equal intervals from 0% to 100% of time. Following the same reasoning, dependent variables were also grouped for all trials, participants and sequences (i.e., increasing and decreasing sequence), for the first (0–49%) and second half (50–100%) of the normalized time series.

ADB and angular velocity of ADB data were subjected, in the second half of the normalized time series, to a two-way mixed-model ANOVA, having two levels of success of the drive (successful and unsuccessful) and nine levels of relative positions to the basket (p1–p9) as, respectively, between- and within-factors (i.e., independent variables). To understand the effect of relative position to the basket and presentation sequence of distinct relative positions to the basket on successful drives, we submitted the mean percentages of successful trials to a two-way factorial ANOVA, with the factors being relative positions (p1–p9) and sequence of presentation (increasing and decreasing). Since this specific analysis involved unequal sample sizes, we followed the suggestions of Langsrud (2003) to use a Type II Sum of Squares analysis in order to prevent factor effects from being confounded with each other. This procedure implied first running ANOVA to obtain interactions between factors, followed by the analysis of each main effect. A Bonferroni adjustment was used for pairwise comparisons of the interaction of relative positions to the basket by success of drive. Violations of the sphericity
assumption for within-participant variables were analyzed using Mauchly’s test. When a violation of this assumption occurred, the Greenhouse-Geisser correction procedure was used to adjust the degrees of freedom.

Finally, we submitted the ApEn values of ADB, separately for successful and unsuccessful trials of the complete time series, to an independent samples t-test for parametric distributions. The level of statistical significance was set at $p < .05$. All statistical analyses were computed using SPSS® 20.0 software (IBM SPSS Inc., Chicago, USA). This study was conducted within the guidelines of the American Psychological Association (6th ed.) and a local university ethics committee approved the protocol.

3. Results

Analysis of angular relations between attackers and defenders in dyads and the basket (ADB) revealed significant interaction effects between the success of the drive of the attackers and the relative position of the dyads to the basket, $F(2.02, 96.86) = 19.39, p < .001, \eta^2 = .29$ (Fig. 3).

Data in Fig. 3 clearly reveals that there were larger values of ADB for successful trials in p6 ($M = 87.76, SD = 58.39$), and smaller values of ADB, for unsuccessful trials, in p3 ($M = -33.53, SD = 23.78$). A Bonferroni adjustment for pairwise comparisons of the interaction effects showed significant differences in ADB, in unsuccessful trials, between p3 and p7 ($p = .01$), p3 and p8 ($p = .04$) and p6 and p7 ($p < .05$). For successful trials, significant differences were found between p2 and p6 ($p < .05$). In line with our hypotheses, and previous research, these results confirmed that attackers were more successful in the task when they explored the left side for moving past the defender, and preferably nearer the center of the court.

We also found a main effect for success of the drive on angular velocity of ADB, $F(1, 48) = 45.43, p < .001, \eta^2 = .49$, indicating that in successful trials, attackers dribbled past defenders with greater angular velocity values ($M = 76.16, SD = 72.12$). In unsuccessful trials attackers tended to present smaller values of angular velocity ($M = -18.40, SD = 142.66$). No main effect was observed for the relative position of the dyads to the basket, $F(3.2, 153.79) = .42, p = .75$. No interaction effects were observed between the success of the drive and relative positioning of the dyads to the basket on the angular velocity of ADB, $F(3.02, 153.79) = 1.38, p = .25$ (Table 1).

Analysis of the success of the attackers’ drives showed no interaction effects between the relative position of the dyads to the basket and the sequence of presentation of start positions, $F(17, 25) = 1.26, p = .30$, and no main effect of relative position of the dyads to the basket, $F(8, 33) = 1.13, p = .37$. How-

![Fig. 3. Estimated marginal means of attacker–defender-basket angle (ADB) for successful and unsuccessful trials according to the nine levels of relative positions to the basket (p1–p9). The vertical represent the standard error.](http://dx.doi.org/10.1016/j.humov.2015.01.003)
ever, we found a main effect for presentation sequence on the success of the drive, $F(1, 33) = 4.87$, $p < .05$. $\eta^2 = .13$, indicating greater values of success for a sequence of decreasing angular relations to the basket ($M = 63.92$, $SD = 26.00$) than for an increasing sequence ($M = 47.21$, $SD = 23.29$). These results suggested that the success of the attackers’ drives increased from the initial sequence (i.e., increasing sequence) to the ensuing sequence of presentation (i.e., decreasing sequence) (Table 2).

Analysis of the structure of variability of angular relations, using values of ApEn of ADB, showed significant differences between successful and unsuccessful drives by the attackers, $t(47) = 3.51$, $p < .01$, $r = .44$, respectively, $M = .29$, $SD = .13$ and $M = .18$, $SD = .09$. These results suggested greater variability in the angular relations between attacker–defender dyads relative to the basket, when the defenders prevented a successful drive by the attackers.

4. Discussion

In this study, we sought to examine the functional exploratory behaviors of individuals in performing in the social collective systems of team sports, seeking to achieve specific performance goals. To achieve this aim, we investigated how attackers and defenders performed in 1v1 dyads in the team sport of basketball by manipulating their co-positioning and angular orientation on court relative to the location of the basket. In line with our hypotheses, and previous research, we noted that in successful trials the attacking player explored more specific spatial areas of performance, such as the left side of the defender to move past him, with greater angular velocity, especially in the center of the court.

We observed that ADB angles were significantly greater in successful trials, and smaller in unsuccessful trials, mainly near the center of the court (p6). This finding suggests that the attackers’ exploration of spatial areas on the left side of the dyad, to break the alignment with a defender and basket, emerged as a more functional solution to approach the target, according to specific court locations. This decision might have emerged from the interaction of information on dyad location with specific personal constraints, since defenders may have tried to prevent right-handed attackers from using their dominant (right) hand to dribble to the right. This solution was likely to provide greater opportunities in 1v1 sub-phases for attackers to achieve their performance goals against the defending opponents. Accordingly, to successfully move past an opponent, attackers may have resorted to the solution of exploring more the left side to break the alignment with the defender and basket when shooting at the target.

Furthermore, significantly greater values of angular velocity of ADB were observed in successful trials for the attacker in the 1v1 sub-phase. It appears that the goal achievement of the attacker

### Table 1

Relative positions to the basket × success of drive Factorial Analysis of Variance for angular velocity of attacker–defender-basket angle (ADB).

<table>
<thead>
<tr>
<th>Effect</th>
<th>Df</th>
<th>F</th>
<th>$\eta^2$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Success of drive</td>
<td>1</td>
<td>45.43</td>
<td>.49</td>
<td>.00</td>
</tr>
<tr>
<td>(B) Relative positions</td>
<td>3</td>
<td>.42</td>
<td>.01</td>
<td>.75</td>
</tr>
<tr>
<td>A × B (interaction)</td>
<td>3</td>
<td>1.38</td>
<td>.03</td>
<td>.25</td>
</tr>
<tr>
<td>Error (within)</td>
<td></td>
<td>153.79</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 2

Relative positions to the basket × presentation sequence two-way Factorial Analysis of Variance for successful drives.

<table>
<thead>
<tr>
<th>Effect</th>
<th>Df</th>
<th>F</th>
<th>$\eta^2$</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Relative positions</td>
<td>8</td>
<td>1.13</td>
<td>.22</td>
<td>.37</td>
</tr>
<tr>
<td>(B) Presentation sequence</td>
<td>1</td>
<td>4.87</td>
<td>.13</td>
<td>.03</td>
</tr>
<tr>
<td>A × B (interaction)</td>
<td>17</td>
<td>1.26</td>
<td>.46</td>
<td>.30</td>
</tr>
<tr>
<td>Error (within)</td>
<td>33</td>
<td></td>
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<td></td>
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</tbody>
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depended, not only on exploring the alignment with the defender and the basket, but also on changing this angular relation quickly to move past the opponent. Previous research has already indicated that other interacting agents provide relevant sources of information (e.g., posture-related information of the opponent) that constrain actions of an individual in social systems such as team sports (Esteves, de Oliveira, & Araújo, 2011; Marsh, Richardson, Baron, & Schmidt, 2006).

We also observed smaller levels of variability in ADB for successful trials of the attacker, in line with other studies (Araújo et al., 2006; Davids et al., 2006). The detection and use of contextually relevant information for moving past a defender may have channeled the search for relevant solutions within the perceptual–motor workspace, leading to a convergence towards a functional performance solution (Newell, 1991). In contrast, greater levels of variability in ADB during successful trials for the defender, emanated from the exploratory behaviors of the attacker in seeking to use information to break the alignment with the opponent, which was apparently ineffective. Our findings revealed how informational constraints may have shaped exploratory behaviors of attacker–defender dyads by reducing the available configurations (i.e., spectrum of possible actions) of the performer–environment system (Davids, 2009). These results are akin to findings of Gel’fand and Tsetlin (1962) on exploration of coordination tendencies in a human movement system during goal-directed behavior. Their data from pistol shooting showed how the search for essential variables became more precisely distinguished, through exploration and adaptation of the relations between the joints of the shooting arm, leading to the successful accomplishment of the task goal.

Interestingly, we observed no evidence of significant differences in the success of the drive of the attacker according to the relative positioning of the dyad to the basket (from p1 to p9). These findings suggest an adaptation of the attackers to the evolving task constraints, that may have led to the emergence of a constant level in performance efficacy, despite the process of goal-achievement being markedly different, as we have reported previously. Complex adaptive systems (here, basketball performers) consistently demonstrate their ability to achieve similar goals with different action patterns, exploiting their evolutionary tendencies for intrinsic system degeneracy (Edelman & Gally, 2001; Mason, 2010; Seifert et al., 2014). However, we found an effect of sequence presentation on the relative positions to the basket (p1–p9) on the success of the drive. The success of an attacker in driving past a defender rose from the initial sequence (i.e., increasing sequence) to the ensuing sequence of presentation (i.e., decreasing sequence), irrespective of the different angular positions to the basket (p1–p9). These results suggest that the success of an attacker’s goal-directed behaviors, during the dyadic interactions, was constrained by the order of presentation of the angular positions to the basket. Stable and less stable organizational states of the system appeared to be constrained by discontinuous changes in the sequence of presentation of the relative positions to the basket, representing a qualitative change in the organization of a dyadic system (Araújo et al., 2006). Previous work has alluded to this tendency of complex dynamical systems as hysteresis (Kelso, 1995). By inhabiting a performance region where different system coordination tendencies may coexist, a social collective system may take advantage of functional and context-dependent information (e.g., angular relations sustained between participants relative to the scoring target) to regulate their coordination dynamics (Kelso & Engstrem, 2006).

To summarize, this study added further empirical evidence to support outcomes of previous investigations on effects of informational constraints, such as values of interpersonal distance and relative velocity, on dyadic system interactions in invasive team ball sports (e.g., Cordovil et al., 2009; Duarte et al., 2010). Here we showed that interpersonal interactions of attacker–defender dyads in the 1v1 sub-phase of basketball were dependent on exploration of the alignment between opponents and a scoring target, associated with the generation of a large angular velocity during performance, by attackers.

Future research on interpersonal interactions in social collective systems needs to consider the effects of additional interacting agents and other potential information constraints on participant behaviors. For instance, in the study of team sport collectives, an interesting question concerns how an attacker might manage the alignment to a marking defender, and to an additional defender positioned near the target, when striving to move closer to the scoring target and complete a shot. In addition, future research could also consider comparing the influence of relevant informational constraints on emergent functional exploratory behaviors in elite and sub-elite performers.
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