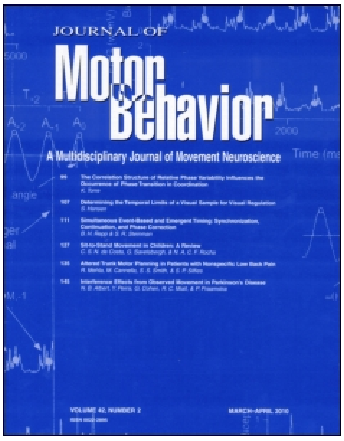


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*RESEARCH ARTICLE*

# Interpersonal Distance Regulates Functional Grouping Tendencies of Agents in Team Sports

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**Abstract.** The authors examined whether, similar to collective agent behaviors in complex, biological systems (e.g., schools of fish and colonies of ants), performers in team sports displayed functional coordination tendencies, based on local interaction rules during performance. To investigate this issue, they used videogrammetry and digitizing procedures to observe interpersonal interactions in common 4 versus 2 + 2 subphases of the team sport of rugby union, involving 16 participants aged between 16 and 17 years of age. They observed pattern-forming dynamics in attacking subunits ($n$ = 4 players) attempting to penetrate 2 defensive lines ($n$ = 2 players in each). Data showed that within each attacking subunit, the 4 players displayed emergent functional grouping tendencies that differed between the 2 defensive lines. Results confirmed that grouping tendencies in attacking subunits of team games are sensitive to different task constraints, such as relative positioning to nearest defenders. It was concluded that running correlations were particularly useful for measuring the level of interpersonal coordination in functional grouping tendencies within attacking subunits.

*Keywords*: complex systems, functional grouping tendencies, interpersonal coordination, interpersonal distance, intrateam analysis



In complex biological systems, it has been observed that individual organisms use relatively simple local behavioral rules to create structures and patterns at a collective level that are more complex than the behavior of individual agents. For example, previous work on schools of fish has revealed that individual agents in complex systems have a tendency to spontaneously organize themselves into rich coordinated patterns by modifying their movements on the basis of local social interactions (Couzin, Krause, Franks, & Levin, 2005). Research has also examined collective behaviors of mixed groups of cockroaches and socially integrated autonomous robots. Behavior of agents, natural or artificial, was perceived as equivalent, and it was reported that collective behaviors in both systems emerged from nonlinear responses over time supported by local interactions rules (Halloy et al., 2007). Local interaction rules define the performance task constraints that stabilize agent behaviors (e.g., agents' relative positioning, remaining close to other system agents but avoiding contact, maintaining locomotion lines toward a target). However, the presence of significant others (i.e., other group members and predators) demands continuously adaptive behaviors, signifying that local interaction rules are not invariant, but rather context dependent. In complex system modeling, this context dependency can be captured through analyzing the dynamics of interpersonal distances between system agents.

In light of this complex system modeling, it needs to be verified whether players in team sports might also regulate actions as individual agents using relatively simple local context dependent rules to create and maintain functional collective structures and coordination patterns (e.g., Passos et al., 2009; Schmidt, O'Brien, & Sysko, 1999).

Some research on interpersonal coordination in the team sport of Rugby Union has begun to identify collective variables and nested system parameters characterizing attacker–defender dyads as self-organized systems (e.g., Passos, Araújo, Davids, Gouveia, Milho, & Serpa, 2008; Passos, Araújo, Davids, Gouveia, & Serpa, 2006). These studies have typically focused on interindividual interactions in 1 versus 1 subphases of team games. This program of work can be advanced by analyzing collective dynamical behaviors involving increasing numbers of agents in more complex subsystem interactions (e.g., subphases of 2 vs. 1; 3 vs. 2; 4 vs. 3). In the present study, we focused on identifying the nature of the functional regulatory information in a competitive performance setting shared by teammates within a particular subunit (e.g., four players displaying a typical attacking diamond shape structure in Rugby Union). It is important to understand that functional information here is context dependent and meaningful in specifying the relations between parts of a complex system. Performing successfully in team games involves acting according to key principles. For example, attacking principles in team sports such as Rugby Union require that performers (a) move forward, toward the goal line; and (b) support the ball carrier. In this study we used the exemplar task vehicle of rugby union to address a key issue: How do performers in a collective system interact with teammates, guided by emerging intrateam functional coordination tendencies that allow them to accomplish attacking principles of play? This issue might be resolved by identifying the intrateam key variables, which capture the interpersonal functional coordination tendencies in a system subunit composed of four players.

## Coadaptation as a Demand for Collective Behaviors

Ideas in ecological psychology suggest that collective actions emerging between agents in sport teams as collective systems are dependent on information available in specific contexts, particularly the information that is created by each individual's tactical actions (Passos, Araújo, et al., 2008).

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Ecological psychology proposes a tight coupling between perception and action in individuals, signifying that, in team sports, an attacker can generate information for action by simply moving. The individual has to act in order to perceive a teammate's behaviors, as well those of a defender, and vice versa. These interactions create coadaptive behaviors in which each performer adjusts his or her own behaviors relative to the perceived actions of neighboring players in order to achieve performance goals (Fajen, Riley, & Turvey, 2009; Kauffman, 1993). This argument highlights how local interactions rules are not invariant but rather context dependent.

In team sport collectives, this coadaptation process is grounded in the need to maintain a functional position relative to a teammate or opponent. Based on other research on collective behaviors in neurobiological systems, it can be hypothesized that a key variable is a functional interpersonal distance between individuals in a subunit. The merit of this variable has been established in research on group coordination processes in biological systems such as schools of fish (e.g., Couzin et al., 2005), or in simulated settings with boids, electronic creatures that virtually simulate the behavior of agents (i.e., birds) in a collective (Reynolds, 1987). This research has formalized the collective behavior of agents following simple interactions rules, including (a) collision avoidance (individuals should avoid collisions with nearby system agents), (b) maintaining velocity (individuals should attempt to match their velocity with nearby system agents), and (c) flock centering (individuals should attempt to remain adjacent to nearby system agents).

It is important to note that some interaction rules might be prescribed by a coach in advance (i.e., players are made aware of the benefits of maintaining a diamond shape in attacking subphases of rugby union). In this respect, instructional constraints encourage performers to acquire and maintain a relative position and interpersonal distance with other players in a subunit. However, the way that players use functional context-dependent information to regulate that rule-governed behavior in a dynamic performance context is based on perception of the actions of nearby players (i.e., teammates). The regulatory information that performers pick up to acquire and maintain functional interpersonal coordination patterns during performance was the subject of this investigation.

## Functional Interpersonal Distance in Rugby Union

Maintaining a functional interpersonal distance is a local interaction rule signifying that each player is attracted toward the closest teammate (exemplifying the characteristic of flock centering in other biological, complex systems). Clearly, dysfunctional collisions between players within the same team should be avoided (i.e., collision avoidance), keeping personal space available to be explored (e.g., the space needed to change a running line or to accelerate to receive the ball whilst running, causing difficulties for defenders). A minimum functional interpersonal distance value is needed for attackers to succeed in these actions. To manage the need for a functional interpersonal distance value, players need to match their movement velocity with that of close teammates. The implication is that when ball carriers increase or decrease running velocity in rugby union, each player in the attacking subunit should also adjust his or her velocity. At this point we would like to reinforce that accordingly with the rules of the game, all the support players must be behind the ball carrier, and this is a task constraint conditioning that all the support players come from behind.

In this study, we examined whether a functional interpersonal distance value might provide a key variable that captures coadaptive behaviors for each individual performer within an attacking subunit in team sports such as rugby union. These coadaptive behaviors require the emergence of functional coupling tendencies between players in an attacking subsystem, which creates information specific to the performance environment that each player within the subsystem must learn to become attuned. With respect to these insights, an additional important technical question concerns how to measure functional coupling tendencies of agents in a social neurobiological system.

By learning to use information to regulate action, information-action couplings can be acquired to adapt behaviors to environmental demands (i.e., a teammate's actions) and allow anticipation to maintain collective goal-directed behavior. However, anticipation is only possible if players are attuned to (i.e., aware of) the most relevant sources of information needed to maintain goal-directed behaviors. To be attuned to the most relevant perceptual variables in a performance context is the basis of functional individual and collective behavior in team sports. For example, attunement allows teammates to increase or decrease running velocity, and change or maintain running line trajectories to keep functional interpersonal distance values between each other (Passos et al., 2009). According to Pfeifer and Bongard (2007), an important aspect of collective behavior in group activities is task redundancy, which is similar to the notion of system degeneracy in neurobiology, highlighted by Edelman and Gally (2001). This idea signifies that the same task (e.g., advance into opposition territory) can be performed in many different ways as needed (e.g., maintaining running line trajectories toward the goal line, supporting the ball carrier, passing the ball). These adaptive behaviors require functional coupling tendencies among neighboring agents within a sports team, considered as a complex system. In rugby union, the main task for players is to carry the ball toward the try line as fast as possible, in accordance with the principles of the game to advance forward and support the ball carrier to ensure the continuity of the attack. However, typically the ball carrier cannot perform this task alone due to the proximity of defenders and needs to pass the ball to a support player, who becomes the new ball carrier. Task redundancy in rugby union signifies that the ball can be continuously carried by different players as the team progresses toward the try line. To exploit task redundancy, players must reorganize themselves into subunits, rotating functional roles such as ball carrier and support player, whose displacement trajectories are constrained by local, context-dependent interaction rules. When this rotation is successfully achieved, each attacking subunit maintains adaptive collective behaviors supported by robust coupling tendencies.

## Evasive Maneuvers and Functional Interpersonal Distances Between Agents

A complex systems analysis of the physics of traffic jams can be used to reveal the balance between preferred and desired direction of players' displacement in subunits of team sports. When there are few cars on the road, vehicles are able to move more freely, speeding up or slowing down as drivers require, and the basic rule is to keep a safe distance to a nearest neighbor (Surowiecki, 2004). Analysis of predator–prey spatial relations in biology has revealed that, in the presence of predators, agents in a complex system tend to perform evasive maneuvers, increasing the unpredictability of their collective behaviors to increase uncertainty, known as the Trafalgar effect (Treherne & Foster, 1981). This idea can be implemented to study collective behaviors exemplified in player displacement trajectories in team sports such as rugby union. As long as there are no defenders in front of them, an attacking subunit of four players can move freely, adopting a straight displacement trajectory to reach the goal line as quickly as possible. However, as distance to nearest defenders decreases, players in the attacking subunit tend to perform evasive maneuvers (e.g., passing the ball and altering displacement trajectories) that allow them to maintain collective goal-directed behavior. Instead of free-flow movement, the attacking subunit produces a constrained pattern of behavior in which each player adjusts displacement trajectory and speed to avoid defenders and maintain close links with nearby teammates. Avoidance behaviors, such as evasive maneuvers in team sports, can lead to fluctuations in functional interpersonal distance values between agents, which might decrease the strength of the functional coupling tendencies among players, disturbing interpersonal coordination within an attacker subunit.

## Measurement of Pattern-Forming Dynamics in Team Sports

Previous research on collective actions in association football has tended to analyze structures and patterns of play as a whole rather than investigating interpersonal dynamics of individual agents acting in subunits (e.g., Gréhaigne, Mahut, & Fernandez, 2001). Gréhaigne et al. proposed the concept of effective play-space, defined as a polygonal area set by drawing a line that linked the players located at the periphery of that play-space at any moment in time. The result is a cloud of points that can be characterized by a center of gravity and two principal axes. The axes can measure for length and prevalent direction related to field dimensions, depicting the width and depth of the cloud (Gréhaigne et al.). The polygonal area's shape is highly dependent on the relative interpersonal distances between nearby players. Although the methods used by Gréhaigne et al. also focused on the importance of the interpersonal distances to understand collective behaviors in team sports, no measurement of the coupling tendencies between players was presented.

In the team sport of rugby union, a desirable formation for an attacking subunit based on the principles of the game resembles a diamond shape structure with the ball carrier in the front. There is one left-side support player positioned with a width and depth relative to the ball carrier, as well as a right-side support player. Both side-support players also need to manage a functional interpersonal distance relative to each other. Finally, the axial support player at the rear needs to regulate interpersonal distances to both side-support players and the ball carrier (Figure 1). The shape of a collective subsystem (if nothing perturbs it) is regulated by the information–action couplings that link each agent within it.

The adjustments of player positioning relative to the ball carrier require information propagation. Localized interactions that occur during performance among team members propagate that information (see Figure 1). The ball carrier explores the performance context searching for action possibilities offered by the environment to the player. In this respect, a key task is to describe the behavioral interactions involved in the pattern-forming dynamics of an attacking subunit of four players in rugby union. Camazine et al. (2001) suggested that behavioral interactions among agents within a complex dynamical system emerge from a balance between attraction that brings agents together as a functional subsystem and repulsion to avoid collision between cooperating agents.

The attraction–repulsion balance seems to suggest the presence of a functional value for interpersonal distance among teammates within a sports team. To examine these ideas, in this study we sought to examine intrateam pattern dynamics in the invasion game of rugby union. It was hypothesized that, in line with principles of the game, collective behaviors of an attacking subunit of four players in rugby union would be governed by emergence of functional interpersonal distances among the ball carrier and support players. The way that players regulate interpersonal distances is context dependent, which means that different task constraints (e.g., presence of teammates or defenders) result in differences in the values of functional interpersonal distances in a subunit. The tendency toward grouping in team games has a function (e.g., to advance into opposition territory) and to maintain this purpose players' actions need to be coupled.

# Method

In our analysis of $(4 \times 2 + 2)$ rugby union attacking subphases near the try line, videogrammetry captured players' motion and TACTO 8.0 software digitized player positions (Fernandes & Malta, 2007). Sixteen male rugby players aged between 16 and 17 years of age participated in the study ($M$ experience = 4.0 years, $SD$ = 0.5 years). Participants were

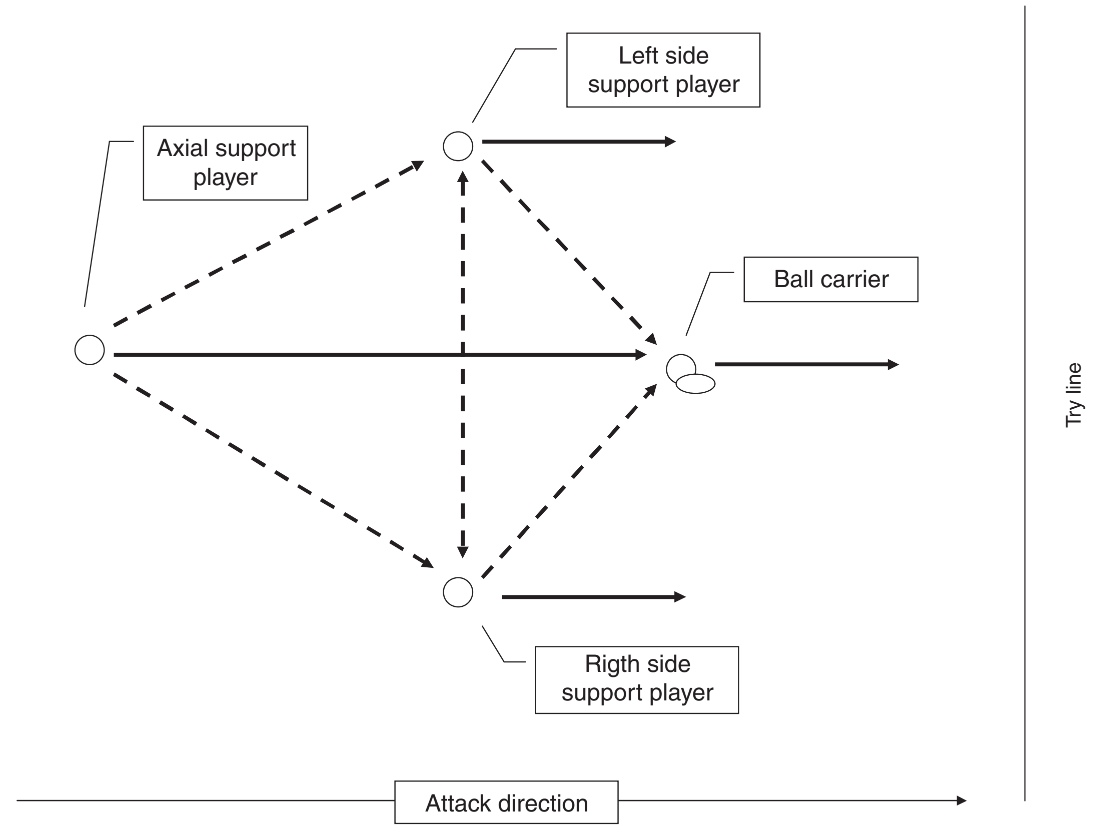


**FIGURE 1.** Diamond shape structure. Black arrows represent the players running line direction and black dash arrows represent each player linkage.



randomly assigned to two groups in which each player acted as both attacker and defender in each trial. To prevent possible fatigue effects on performance, each group (i.e., attacker and defenders) performed three trials in row, after which they changed roles and performed another three trials. This protocol allowed us to observe interpersonal interactions in 18 different trials.

An experimental task was designed that was representative of a typical subphase of rugby union (i.e., the 4 vs. 2 + 2 situation near the goal line). In this subphase, a group of four rugby players formed an attacking group and two pairs of opponents formed a first and second defensive line (aiming to cover a larger area of the playing field, the two defensive lines are a present practice in tactical defensive actions in rugby union; usually performed by the fullback and the wingers). There were two performance aims: (a) attackers were asked to place the ball on the ground with the hand in the try area, and (b) defenders were asked to stop the attacker's progression toward the try line within the rules of rugby union. No other specific advice was given to each participant on how to achieve these aims so that we could observe the spontaneous interpersonal interactions of teammates without overprescriptive instructions. Following procedures of Biscombe and Drewett (1998), field dimensions were established for 4 versus 2 + 2 subphase practice tasks as 22 m depth and 10 m width (Figure 2).

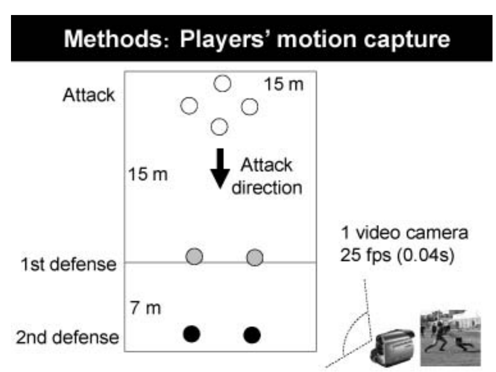


**FIGURE 2.** Task design. White circles represent the four attack players, grey circles represent two defenders in the first defensive line, and black circles represent two defenders in the second defensive line.

The developing athlete sample was selected for study because we needed players who knew how to perform basic relevant actions in rugby union, and preferably who were not so skilled or unskilled as to display idiosyncratic movements that were unique to an individual (i.e., not novices or experts). Players' motion was captured by a single digital video camera (Sony DC-TRV16). The ball used was size 5, as recommended by the International Rugby Board for this age group. To synchronize timing of player motion in each trial, digital video images of action were acquired by a computer, via a FireWire cable, by using the Pinnacle Studio version 8.0 SE software and saved as AVI files. For image treatment, TACTO 8.0 software was used for digitizing at 25 frames per second (Fernandes & Malta, 2007). Digitizing started at a specific frame in each trial when the attacker touched the ball with the foot before moving toward the try line. TACTO 8.0 allowed us to plot the coordinates of each player in the performance field, by extracting the players' bidimensional coordinates in each frame of a video stream by following the working point with the mouse cursor. The working point was a projection on the floor of the center of the mass of each player. The camera was placed above the performance area, on a balcony with a height of 4 m. Due to the camera position related to the players' plane of motion, there were no image occlusion problems. For the reconstruction of the bidimensional space, we followed the methods of Passos, Lopes, and Milho (2008). The estimated error for the digitizing procedures was 0.357 m, which corresponds to a relative error of 0.2%.



### Measuring Grouping Tendencies: Functional Interpersonal Distance

To test agent-grouping tendencies, functional interpersonal distance was calculated through plotting the mean of the interpersonal distances among the four players within the attacker subunit. This functional is defined asin which $np = 4$ is the number of players and $d_{ij}$ is the interpersonal distance between different players $i$ and $j$, for which distances are obtained considering the players' combinations.To test the context dependency of the interpersonal distances within an attacker subunit, this variable was analyzed under different task constraints: (a) before the first defensive line and (b), between the first and second defensive lines. To measure the performance differences a $t$ test assuming unequal variance was performed on the data.

### Measurement of Interpersonal Coordination Tendencies

*Measuring Players' Interpersonal Coordination on Time*

To describe the interpersonal coordination tendencies among players within attacking subunits, we used running correlations, which is a technique to capture continuous changes in coordination between system components over time (Corbetta & Thelen, 1996). Thus, running correlations were applied to analyze the performance of each possible dyad of attackers within the same attacker subunit (i.e., for a subunit of four players we observed a total of six pairs of attackers). Sustained on the first principle of the game (i.e., to advance in the field), the variable examined in the running correlations was the distance of each attacker to the try line (e.g., Attacker 01 Distance to try line correlated with Attacker 02 Distance to try line) for each entire trial (10 s window size). A continuous correlation function was obtained that described ongoing coordination (i.e., coupling tendencies) in dyadic patterns over time. Plotting the running correlations for each attacker–attacker dyad for the eighteen 4 versus 2 + 2 trials resulted in a total of 108 data plots.

*Measuring the Strength of Coupling*

The aim of this analysis was to calculate a value that could accurately measure the strength of coupling among two players within the same subunit. The same dyads of attackers analyzed with running correlations were used in this analysis. In each dyad we plotted the distance of one attacker to the try line as a function of the distance to the try line of the other attacker. After that we added a trend line to the data and the $r^2$ value was used as a measure of the strength of the coupling among players in each attacker–attacker dyad. As with other analyses, when we plotted data for each attacker–attacker dyad over eighteen 4 versus 2 + 2 trials, we had available a total of 108 $r^2$ values.

## Results

The data revealed differences in the mean values of interpersonal distance within an attacker subunit before and after the first defensive lines. As a subsystem coordination measure, the running correlations revealed that players were alternatively coupled (i.e., in in- and antiphase modes). The regression analysis revealed that players were coordinated with high values of interindividual coupling.

### Functional Interpersonal Distances

We analyzed interpersonal distance measures to evaluate the veracity of the first hypothesis, that interpersonal distances are context dependent. The means and standard deviations (i.e., the grey error bars) of interpersonal distance values were calculated before the attacker subunit passed the first defensive line (i.e., black squares on Figure 3), and before it passed the second defensive line (i.e., white squares on Figure 3) over trials.

In Figure 3, the data indicated that, before the attacker subunit passed the first defensive line, 14 of the 18 trials (i.e., 77.7%) displayed a mean range between 2 to 4 m of interpersonal distance values (i.e., black squares). In 12 of the 15 trials (80%), when the attacking subunit faced the second defensive line, a change in the range of interpersonal distance from 3 to 5 m was observed. Figure 4 shows a decrease in standard deviation values after the attacker subunit passed the first defensive line in 12 of the 15 trials.

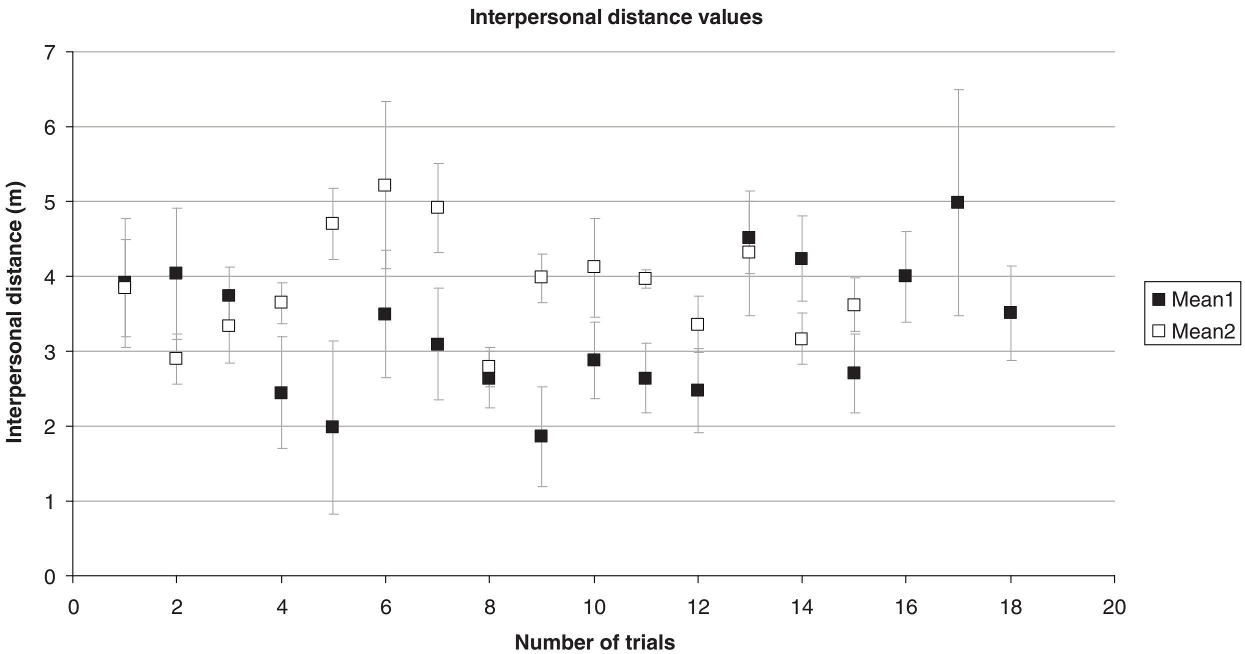


**FIGURE 3.** Interpersonal distance values. The black squares represent the mean interpersonal distances of the attacker subunit on each trial, before passing the first defensive line. The white squares represent the mean interpersonal distances of the attacker subunit on each trial, before passing the second defensive line. The error bars represent the standard deviation of the interpersonal distance of the attacker subunit on each trial.



Results from the *t* test reinforced the qualitative analysis. The mean values of interpersonal distance before the first defensive line ($M = 3.28$; $SD = 0.75$) were significantly different, $t(31) = 2.04$, $p = .05$, to the interpersonal distance values recorded between the first and the second defensive line ($M = 3.86$; $SD = 0.50$).

### Running Correlations

Due to *r* values oscillating between 1 and –1, the data revealed that each attacker–attacker dyad was continuously coordinated over time. Values of *r* close to 1 signified that both players were decreasing the distance to try line at the same rate; values of *r* close to –1 signaled that one player was decreasing the distance to the try line, whereas the other player in the dyad was increasing the distance to the try line. However, we would like to emphasize that a small adjustment in the support player's trajectory implies a slight increase in the distance to the goal line, represented as a negative correlation value. Whereas neither decreasing nor increasing the distance to the try line reveals no correlation (*r* value close to zero). Figure 4 displays exemplar data of the running correlation from the six possible combined dyads within an attacker subunit. Initial *r* values close to 1 signified a positive relationship that was initially exhibited, but that, with decreasing interpersonal distance between attackers and defenders over time, *r* values began to oscillate between 1 and –1.

Additionally, Figure 5 displays the landscape of the running correlations for the same attacker subunit. Each line corresponds to each dyad trajectory analysis.

Data revealed in- and out-phase coordination tendencies among players due to values of the correlation coefficient oscillate between –1 and 1.

### Measuring the Strength of the Coupling Tendencies

The regression analysis values revealed that 92% of the attacker–attacker dyads displayed $r^2$ values above 0.9, which signified that over 90% of the behavior of one player in the dyad was explained by the behavior of the other player. However, it is also worth noting that 7% of the attacker–attacker dyads displayed $r^2$ values equal to or below 0.9. Figures 6A and Figures 6b display two exemplar situations.

Figure 6A displays the interactions of an attacker–attacker dyad with $r^2$ values above 0.9 whereas Figure 6b displays those of an attacker–attacker dyad with $r^2$ values below 0.9.

## Discussion

Similar to outcomes in other research on collective behaviors in team sports, our data pointed to the existence of functional levels of interpersonal distance between players in an attacker subunit, using the team sport of rugby union as a task vehicle. The analyses showed that functional values of interpersonal distance differed during performance un-

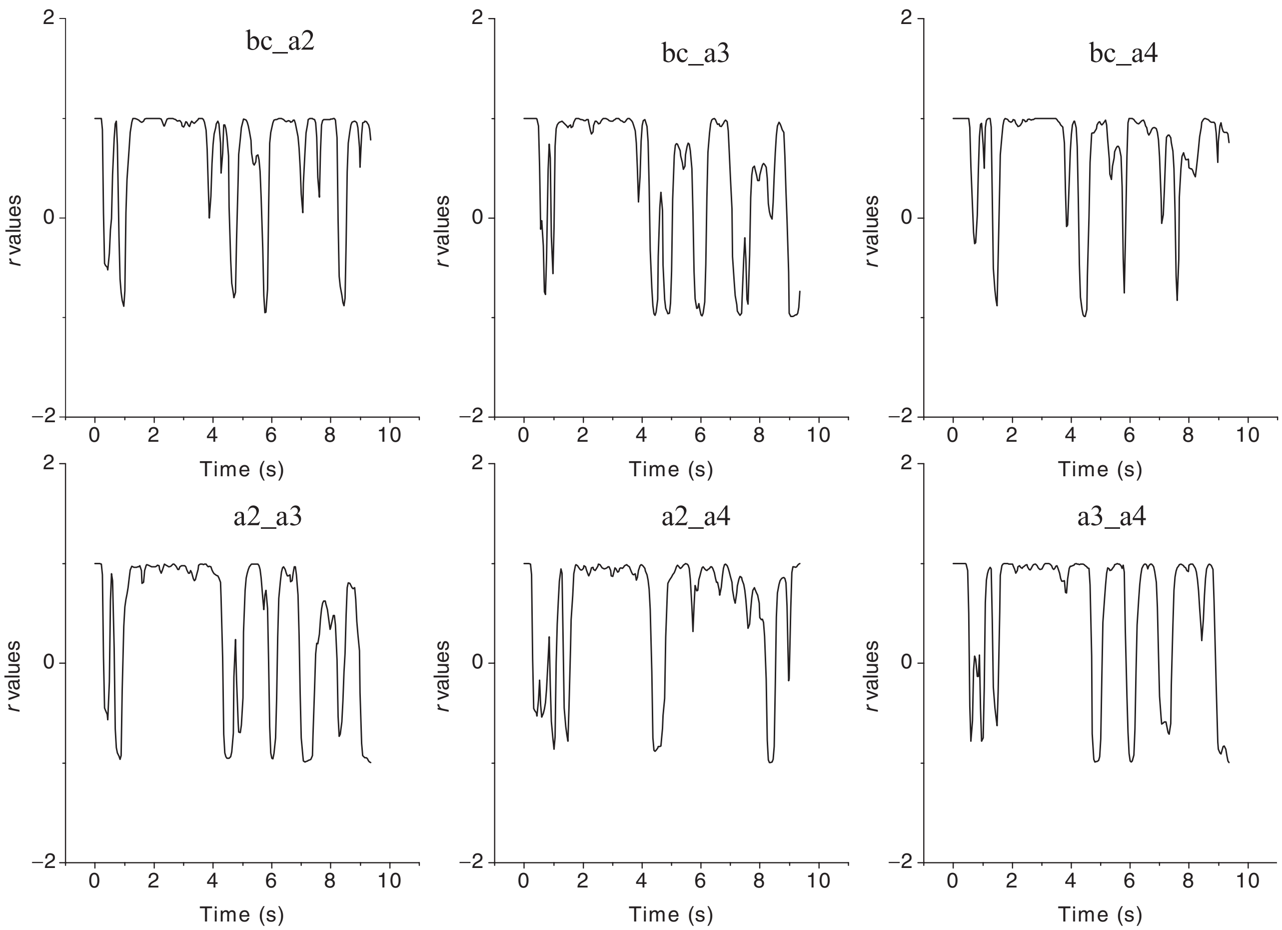


**FIGURE 4.** Running correlations. Exemplar data from the six dyads within an attacker subunit are the following: bc = ball carrier, a2 = right-side support player; a3 = left-side support player; a4 = axial support player.



der varying task constraints, such as coordinating attacking actions before and after defensive lines. In general, results showed that, when players in attacking subsystems in team sports coordinated movements, their behaviors are attracted to, and therefore constrained by, functional values of interpersonal distance to nearby opponents.

The aim of this study was to explore how players interacted with teammates in emerging intrateam coordination states when attacking in rugby union and examine whether those coordination patterns were sensitive to differences in specific task constraints (such as the proximity of opponent players). We sought to analyze how local behavioral rules, such as the maintenance of functional interpersonal distances, are managed under different task constraints in 4 versus 2 + 2 subphases in rugby union (i.e., play before and after a first defensive line). To maintain functional interpersonal distances, players displayed coadaptive behaviors that were captured by analyses of running correlation values. Additionally, analyses revealed that coefficient of determination values ($r^2$) were accurate measures of the strength of coupling among players.

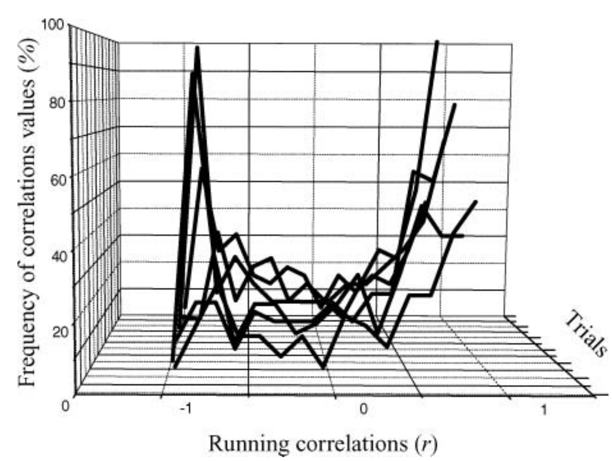


**FIGURE 5.** Landscape of coordinated patterns within an attacker subunit.

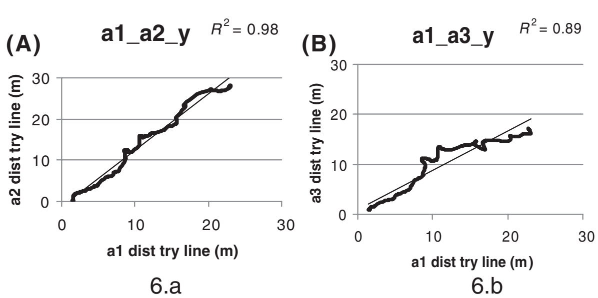


**FIGURE 6.** Coupling tendencies among attackers in the same subunit: (**A**) the regression values ($R^2$) of the distance to the try line, between the ball carrier (a1) and the right-side support player (a2); and (**B**) represents the regression values ($R^2$) of the distance to the try line, between the ball carrier (a1) and the left-side support player (a3). Dist = distance.

## Grouping Tendencies in Rugby Union

As with previous studies of other complex, biological systems (e.g., Couzin et al., 2005; Reynolds, 1987), the data in our analysis of team sports demonstrated that interpersonal distances form a crucial variable that influences agents' collective behaviors. Results suggested a tendency for functional interpersonal distances (e.g., between 2 and 4 m of mean interpersonal distance before the first defensive line) to emerge spontaneously between agents in attacking subunits. The data suggested that performing before the first defensive line and performing inside both the defensive lines (i.e., between the first and second defensive lines) is an important task constraint, leading to significant differences in mean interpersonal distance values in the attacker subunit. Mean interpersonal distance values altered due to changes in game task constraints highlighting a context dependency of performer behaviors. This task constraint required that agents in each attacker subunit displayed functional coadaptive behaviors, leading to a change in the range of interpersonal distance within the attacking subunit: from 2 to 4 m before the defensive line to from 3 to 5 m of interpersonal distance inside the defensive lines. One key issue that needs to be explored in further studies is the decrease in the standard deviation values observed in these data. In this typical 4 versus 2 drill, the decreasing standard deviation values observed after the attacking subunit passed the first defensive line seem to suggest that inside the defensive line each player within the attacker subunit tried to maintain greater stability of interpersonal distance with teammates. However, this interpretation needs more data to be confirmed. These observations supported the hypothesis of the existence of functional interpersonal distance values that characterize the collective goal-directed behavior of players in team sports. To achieve these bounded values of functional interpersonal distance players' actions must be coordinated, and to analyze interpersonal coordination tendencies within each attacker subunit in more detail, running correlations were performed.

## Functional Interpersonal Distances Demand Interpersonal Coordination

After some initial adjustments (for approximately 1 s) all the agents in the six dyads acquired a pattern of coordination characterized by $r$ values close to 1. This observation signified that the four attackers in the subunit were running toward the try line at the same pace, a pattern that remained in place for nearly 4 s (see Figure 4). However, with increasing proximity to the defensive lines, especially inside the defensive lines, the attackers needed to perform evasive maneuvers, which required an increase in coadaptive behaviors within the attacker subunit. Changes in the interpersonal coordination patterns due to these adaptive behaviors were captured with running correlation values oscillating between 1 and –1 (between 4 and 10 s; see Figure 4). This finding demonstrated the presence of a Trafalgar effect in team sport systems. The observations corresponded with data observed in research on predator–prey spatial relations in biology. In the presence of predators, agents within a complex system tend to perform evasive maneuvers, increasing the unpredictability of collective behaviors to increase uncertainty (Treherne & Foster, 1981).

These findings suggested that collective behaviors in team sports such as rugby union, here exemplified in a 4 versus 2 drill, are sustained by coadaptive emergent processes among players within functional performance subunits. The data confirmed the view that, in interpersonal coordination patterns of subunits of team sports, interacting agents are coupled by information fields.

Increasing proximity to defensive lines demanded coadaptive behaviors with changes in the attackers' relative positioning and roles within the subunit. This observation signified that the strength of coupling between agents within a subunit might be decreased, as quantified by $r^2$ values. The present data revealed high $r^2$ values for the majority of the attacker–attacker dyads, which makes sense because all players were running toward the try line (their actions were constrained by the first principle of the game: to advance forward; see exemplar data in Figure 6A). The few $r^2$ values below or equal to 0.9 signified that some players were tackled, remaining on the floor, or passed the ball to a support player. But these players did not perform in accordance with the second principle of the game: support the ball carrier (see exemplar data on Figure 6B). These data suggested how the coefficient of determination ($r^2$) values can be used in further research as a variable to differentiate the behaviors of players inside and outside a specific subunit.

Our findings suggested that when defenders disturbed the stability of an attacker subunit, this subsystem attempted to regroup to maintain goal-directed behaviors. In this typical 4 versus 2 performance drill, the grouping tendencies were strongly constrained by the players' initial relative positioning, but were also context dependent due to individuals continuously performing in accordance with the principles of the game. This observation was supported by the findings that players moved closer together to face the first defensive line and diverged to face the second defensive line. Despite the tactical formation being typically prescribed beforehand by coaches, the way that each player individually used crucial variables for grouping, such as interpersonal distances, is highly context dependent under important specific rules such as remain close to a teammate, avoid contact with the individual, and advance quickly to the try line. This type of context dependency was empirically displayed in this typical 4 versus 2 drill in the significant differences in the values of mean interpersonal differences before and between defensive lines. It was also exemplified by the oscillation of interpersonal coordination patterns (i.e., $r$ values) for each dyadic situation within each attacker subunit (see the coordination patterns landscape in Figure 5).

This outcome showed how deterministic training solutions, such as prescribing specific actions in performance drills for players to imitate, is not a functional method for developing coadaptive agent behaviors in dynamic competitive performance environments. These findings raised some issues regarding more traditional psychological models of individual and team behavior, which presuppose that cognitive processes, such as decision making, are mainly internalized in performers, where perception and action are disconnected subsystems mediated by mental representations of the outer world stored in the brain (Fiore & Salas, 2006; Ranyard, Crozier, & Svenson, 1997). Conversely, training solutions to improve adaptive, collective system behaviors should create better learning environments. These results highlight that functional attacking actions before a defensive line are not the same as functional actions inside defensive lines, and learning environments should be designed accordingly.

To conclude, the existence of functional values of interpersonal distance in intrateam attacking subunits of performers has been highlighted in this study. This observation needs further work to be confirmed, perhaps through a comparative analysis of subunit behaviors in a typical 4 versus 2 drill with the performance of similar subunits in actual competitive performance situations. To conclude, similar to findings from previous research on pattern-forming dynamics in team sports, it seems that spontaneous functional grouping tendencies among agents within sports team collectives exist, which players and coaches can harness to enhance strategic planning and preparation for teamwork and performance.



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