Information-governing dynamics of attacker-defender interactions in youth rugby union

Pedro Passos a, Duarte Araújo b, Keith Davids c, Luis Gouveia c, João Milho a, Sidónio Serpa a

a Faculty of Physical Education and Sports, Lusófona University of Humanities and Technologies, Lisbon, Portugal
b Faculty of Human Kinetics, Technical University of Lisbon, Lisbon, Portugal
c School of Human Movement Studies, Queensland University of Technology, Brisbane, QLD, Australia

First Published: November 2008

To cite this Article: Passos, Pedro, Araújo, Duarte, Davids, Keith, Gouveia, Luis, Milho, João and Serpa, Sidónio (2008) 'Information-governing dynamics of attacker-defender interactions in youth rugby union', Journal of Sports Sciences, 26:13, 1421 — 1429

To link to this Article: DOI: 10.1080/02640410802208986

URL: http://dx.doi.org/10.1080/02640410802208986

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Information-governing dynamics of attacker–defender interactions in youth rugby union

PEDRO PASSOS¹, DUARTE ARAÚJO², KEITH DAVIDS³, LUIS GOUVEIA⁴, JOÃO MILHO¹, & SIDÔNIO SERPA²

¹Faculty of Physical Education and Sports, Lusófona University of Humanities and Technologies, Lisbon, Portugal, ²Faculty of Human Kinetics, Technical University of Lisbon, Lisbon, Portugal, ³School of Human Movement Studies, Queensland University of Technology, Brisbane, QLD, Australia and ⁴Faculty of Pharmacy, University of Lisbon, Lisbon, Portugal

(Accepted 16 May 2008)

Abstract
Previous work on dynamics of interpersonal interactions in 1 vs. 1 sub-phases of basketball has identified changes in interpersonal distance between an attacker and defender as a potential control parameter for influencing organizational states of attacker–defender dyads. Other studies have reported the constraining effect of relative velocity between an attacker and defender in 1 vs. 1 dyads. To evaluate the relationship between these candidate control parameters, we compared the impact of both interpersonal distance and relative velocity on the pattern-forming dynamics of attacker–defender dyads in the sport of rugby union. Results revealed that when interpersonal distance achieved a critical value of less than 4 m, and relative velocity values increased or were maintained above 1 m s⁻¹, a successful outcome (i.e. clean attempt) for an attacker was predicted. Alternatively, when values of relative velocity suddenly decreased below this threshold, at the same critical value of interpersonal distance, a successful outcome for the defender was predicted. Data demonstrated how the coupling of these two potential, nested control parameters moved the dyadic system to phase transitions, characterized as a try or a tackle. Observations suggested that relative velocity increased its influence on the organization of attacker–defender dyads in rugby union over time as spatial proximity to the try line increased.

Keywords: Interpersonal coordination dynamics, nested control parameters, phase transitions, pattern formation, rugby union

Introduction
Despite the enormous variability and complexity of social interactions in dynamic performance environments, theory and experimental evidence points to the existence of pattern-forming dynamics in interpersonal interactions (e.g. Schmidt, O'Brien, & Sysko, 1999). For example, organized structures, such as offensive and defensive patterns in team sports, can emerge in the complex interpersonal interactions of performers regulated through their perceptual processes (for a theoretical overview, see Kugler & Turvey, 1987; see also Araújo, Davids, Bennett, Button, and Chapman, 2004; McGarry, Anderson, Wallace, Hughes, & Franks, 2002; McGarry & Franks, 2007). These ideas signify that in team ball sports the interpersonal dynamics of players cooperating or competing in a dyad or subgroup can be observed in different performance sub-phases, each constraining the coordination of different players to different extents (Schmidt et al., 1999). Based on these insights from dynamical systems theory, the behaviour of interacting players in team games could be interpreted as an emergent process resulting from the spatio-temporal relations established during competitive performance sub-phases. For example, two players in a dribbling dyad (i.e. an attacker with the ball and a defender) may be considered as a single system with dyadic synergy (Schmidt et al., 1999). Dyadic synergies, in the form of attacker–defender interactions, can display non-linear properties, including entrainment and sustained periodic behaviour, and specific modes of interpersonal coordination can emerge under the influence of contextual, personal, and task constraints, such as specific field markings and rules of the game (McGarry & Franks, 2007).

Based on these theoretical insights, some researchers have attempted to model emergent pattern-forming dynamics of goal path selection and decision
making in dyadic (1 vs. 1) sub-phases of various team sports, including basketball and rugby union (see, for example, Araujo et al., 2004; Davids, Button, Araujo, Renshaw, & Hristovski, 2006; Davids, Button, & Bennett, 2008; Passos, Araujo, Davids, Gouveia, & Serpa, 2006; Passos et al., 2008a). This ongoing research programme, involving ideas from complexity theory, evolutionary biology, ecological psychology, and non linear dynamics, characterizes decision making as an emergent property of self-organizational processes in dynamical interpersonal interactions.

For example, in the team ball game of basketball, the interactions of a dribbler and a defender in a 1 vs. 1 situation can result in a relatively stable interactive dynamic structure, since the defender may counteract any movement towards the basket by the attacker. According to coaching literature, it is this stable balance between attackers and defenders that characterizes the 1 vs. 1 sub-phase in basketball (Bain, Hayes, & Quance, 1978). In this game phase, the attacker needs to destabilize or perturb the stable state of a spontaneously formed dyad, resulting in the appearance of a property of dynamical systems – critical fluctuations – that probe system stability. If this system is successfully destabilized (i.e. when the critical fluctuations are powerful enough to break the existing attacker–defender balance), the attacker can dribble past the defender towards the basket. Destabilization exemplifies a symmetry-breaking process whereby previously stable states of interpersonal coordination (i.e. the attacker was the player furthest from the basket) transit to a new dynamic state of organization (i.e. the attacker is now the player closest to the basket with the ball) (Kugler & Turvey, 1987). Transitions from one ordered state where the defender has the advantage to another where the attacker has the advantage (after dribbling past the defender) provides the potential for a bio-physical explanation of decision making and action in team sport.

This order–order state transition can be accurately described by order parameters or collective variables that can be used to depict the functional order in complex systems (Haken & Wunderlin, 1990). In other words, collective variables accurately capture and describe the collective behaviour of the attacker–defender system. Control parameters are those variables that drive a complex system through different states of order (Kelso, 1995). They can explain why an attacker–defender dyadic system remains in balance or, in contrast, why an attacker gains an advantage and passes a defender, creating a phase transition in system order. In their previous work on emergent decision making in the sport of basketball, Araujo and colleagues investigated potential control parameters for moving attacker–defender dyads in 1 vs. 1 sub-phases through different states of organization (Araujo, Davids, Sainhas, & Fernandes, 2002; Araujo et al., 2004). Analysis of experiential knowledge in the expert coaching literature in basketball (e.g. Bain et al., 1978) reveals that a potential control parameter for an attacker–defender system is the intrinsic metric of the interpersonal distance between the attacker and defender in a 1 vs. 1 dyad. This metric system is “action-scaled” (Konczack et al., 1992), because the dimensions formed by each individual attacker–defender dyad will differ (due to physical variations of performers such as height and limb lengths). The use of an intrinsic metric signifies that the critical value of the control parameter might change depending on the action-scaled features of a specific attacker–defender system.

Following the insights of initial work by Araujo et al. (2004), more recent research (Passos et al., 2006) established the utility of three-dimensional methods of analysis for examining the presence of dynamical systems properties, such as phase transitions and critical fluctuations, under the unique performance task constraints of rugby union. Passos and colleagues (2008a) studied interpersonal interactions in rugby union to model control parameter and order parameter relations in attacker–defender dyads under different task constraints than basketball, such as the different rules of each game, different ball shape and size, and different playing area dimensions. Results revealed that the behaviour of both players in attacker–defender dyads in rugby union emerged through exploration of the context. The findings of Passos et al. (2006, 2008a) reveal the influence of another potential control parameter on interpersonal dynamics – the “relative velocity” between participants in a dyad – reinforcing the importance of studying the influence of different task constraints in team sport contexts. In the rugby union research of Passos et al. (2008a), relative velocity was defined as the difference between the running line speed of an attacker and a defender in a dyad. Relative velocity values were derived by calculating the differential between attacker velocity and defender velocity. Under the distinct task constraints of rugby union (e.g. physical contact is allowed according to the rules of the game; the ball can only be passed backwards; players can run with the ball in the hands), it was observed how attackers used velocity to create fluctuations leading to phase transitions in attempts to destabilize dyadic systems. These observations suggested that the control parameter influencing system organization in sub-phases of different team sports might be significantly shaped by different task constraints.

Taken together, the findings from extant research in basketball and rugby union suggest the existence...
of a number of potential control parameters in interpersonal dynamics of attacker–defender dyads in team sports. To date, there have been no attempts to compare the relative effects of different potential control parameters under the same task constraints in competitive team games. In the present study of interpersonal dynamics of attacker–defender dyadic systems in rugby union, the influence of two candidate control parameters identified in previous work was assessed: interpersonal distance and relative velocity. The main aim of the present study was to determine how interpersonal coordination patterns in attacker–defender dyads, exemplifying outcomes such as tries or tackles, emerge in performance. Another specific aim of this ongoing research programme was to study pattern-forming dynamics in different team sports and to identify relevant order and control parameters that accurately describe dyadic system behaviour under distinct performance task constraints.

Methods

Eight male rugby players aged 11–12 years participated in the study (mean number of years of rugby practice = 4.0, s = 0.5). Each player acted as both attacker and defender in dyads, and they participated (in randomly assigned pairs) with other participants in different dyads. To prevent possible fatigue effects on performance, it was decided that each dyad would perform three trials, allowing us to observe the responses of 48 different dyads.

An experimental task was designed that was representative of a typical sub-phase of rugby union with the minimum number of players involved (i.e. the ubiquitous 1 vs. 1 situation near the try line). In this sub-phase, a pair of rugby players with opposing functions and goals momentarily forms a dyad: (i) the attacker aims to place the ball on the ground with the hand over the try line; (ii) the defender aims to stop the attacker’s progression towards the try line within the rules of rugby union. Following the procedures of Biscombe and Drewett (1998), the depth and width of the field for the 1 vs. 1 sub-phase practice tasks were set at 10 m and 5 m respectively. This information helped us to construct the task constraints of the experimental work in our study.

All players were selected for the study because they knew how to tackle (i.e. complete the action of intercepting the attacker and stopping his progression towards the try line within the rules of the game). Players’ motion was captured by two digital video cameras (Sony DC-TRV16). We used a size 5 ball as recommended by the Portuguese Federation of Rugby Union for this age group. In filming sports actions, Bartlett (1997) suggested that the angle between cameras should vary between 60° and 120°. Those deviations are tolerated (relative to 90° of the optimal position) to record the appropriate image of both players. To synchronize the images recorded by both cameras in each trial, the specific frame when the attacker touched the ball with the foot before initiating the movement towards the try line was used. Digital video images of action were acquired by a computer, via fire wire, by using the Pinnacle Studio version 8.0 SE software and saved as AVI files. For image treatment, the software Tacto 7.0 was used with digitization at 25 frames per second (Fernandes & Caixinha, 2003).

The Tacto 7.0 software allowed us to plot the coordinates of each player in the dyad, providing extraction of the players’ bi-dimensional coordinates in each frame of a video stream by following the working point located in the middle of the abdominal area with the mouse cursor. The two sets of bi-dimensional coordinates (one for each video stream) were fed to a previously trained artificial neural network (ANN) to calculate the three-dimensional coordinates, as described previously by Passos et al. (2006). This network consisted of four input neurons, corresponding to the four coordinates of stereo images for each player (e.g. two from the frontal camera (x1, y1) and two from the transverse camera (x2, y2)), six neurons in a hidden layer, and three output neurons, corresponding to the real coordinates x, y, and z (Memon & Khan, 2001).

To ensure accuracy of the output information of an artificial neural network, a prior stage of training was required. This training consisted of feeding the network inputs with known stimuli (e.g. bi-dimensional coordinates of a set of points in two images) and adjusting the net node weights to match the actual outputs to the desired response (e.g. the corresponding set of spatial coordinates). The node weight adjustment was accomplished by using the backpropagation algorithm to minimize the sum of the square differences between the actual output and the desired output (Haykin, 1994). The ANN training procedure required knowledge of the actual coordinates of a set of points lying within the specified performance area, and for this purpose a cube-shaped reference structure was used to extract the data (using 12 rods each 1.8 m long) as suggested by D’Appuzo (2002). The reference structure was moved to cover the entire surface/volume of the performance field allowing the extraction of 330 points, of which 108 were used in the training and validation procedure of the artificial neural network.

To evaluate network accuracy, we estimated whether the coordinates of a given point in the model corresponded to the actual coordinates of that same point. The difference between the predicted and actual coordinates (plotted with a set of points
not used in the training procedure) was used to calculate the root mean square error (RMSE), providing a measure of accuracy. The lower the mean RMSE value, the more accurate is the network. The average RMSE had a value of 1.3 cm, which was acceptable for the stated purpose of this research study, and was small enough to avoid a measurement bias in coordinate estimation.

Precision can be defined as the closeness of the predicted coordinates when a point is digitized (in both video streams) several times (Passos et al., 2006). Ideally, the predicted coordinates should be identical every time a particular point is digitized. Precision is commonly quantified by the standard deviation of a set of predicted three-dimensional coordinates for each particular digitized point. The obtained pooled standard deviation was 0.03 m, which is an acceptable value since it corresponds to 0.3% of the length of the field of play.

As stated previously, the main aim of this study was to analyse the relative influence of two candidate control parameters identified in previous research – interpersonal distance and relative velocity – on pattern-forming dynamics of an attacker–defender dyad. The data used to calculate relative velocity, as well as interpersonal distance, were supported by observation of non-linear time-series of players’ trajectories on the field of play, extracted through videogrammetry techniques. Conventional statistical analyses are not able to deal with non-linear characteristics of time-series due to assumptions of the data. To analyse how the relative influence of two potential, nested control parameters described how a certain outcome emerged in the pattern-forming dynamics (i.e. a clean try; an unsuccessful tackle; and an effective tackle), we decided to express observations with phase plots of relative velocity as a function of interpersonal distance. Phase plots were constructed using interpersonal distance on the x axis and relative velocity on the y axis to capture pattern-forming dynamics of the dyad over the timescale of perception and action.

**Results**

**Interpersonal distance analysis**

To study interpersonal dynamics of decision making and action in attacker–defender dyads in team sports, it was decided to first identify an order parameter (i.e. collective variable) to describe dyadic system behaviour – that is, a vector connecting each player in the dyad (Passos et al., 2008a). Data from the order parameter analysis allowed us to identify three different outcomes (i.e. coordination patterns) of dyadic pattern-forming dynamics: (i) effective tackle; (ii) tackle with the attacker passing the defender; and (iii) clean try (Passos et al., 2008a).

When a try was scored, a sudden decrease in interpersonal distance was observed, stopping 2–3 s after the trial was initiated. For an effective tackle, interpersonal distance remained close to zero metres, but no zero crossing occurred (see Figure 1a). For a tackle where the attacker eventually passed the defender (see Figure 1b), a sudden decrease in interpersonal distance was observed, which slowed down 2.5–3 s after trial initiation. At that time a zero crossing took place (i.e. the moment where the attacker passed the defender), with the relative interpersonal distance assuming negative values, but remaining between 0 and −2 m. When a try was scored (Figure 1c), and similar to previously observed dyad dynamics, interpersonal distance decreased abruptly, but in a continuous fashion with a zero crossing occurring after 2 s.

**Relative velocity as a potential control parameter**

Our analysis focused on the data between the two vertical black dashed lines (between these lines the critical moment for the attacker’s decision to move forward and attempt to pass the defender was captured). Figure 2a, which represents the scoring of a try, shows that close to 3.5 m of interpersonal distance, the attacker’s velocity increased up to 5 m · s⁻¹, while the defender’s velocity decreased.

Figure 1. Interpersonal distance over time. (a) Effective tackle; (b) tackle but the attacker passes the defender; (c) clean try.
to 2 m $\cdot$ s$^{-1}$. In contrast, during the tackle scenarios, at close to 2.4 m of interpersonal distance during an unsuccessful tackle (i.e. where the attacker was tackled but passed the defender; see Figure 2b) and close to 2.3 m of interpersonal distance for a successful tackle (see Figure 2c), the attacker’s velocity decreased to values of approximately 2 and 1.5 m $\cdot$ s$^{-1}$ respectively, while the defender’s velocity increased to 1.5 m $\cdot$ s$^{-1}$.

From Figure 3a it can be observed that within 4 m of interpersonal distance, relative velocity values increased or were maintained above 2 m $\cdot$ s$^{-1}$, which is consistent with the scoring of a try. In Figure 3b it can be observed that, within 4 m of interpersonal distance, relative velocity increased up to approximately 2.5 m $\cdot$ s$^{-1}$ but then began decreasing consistently to below 1 m $\cdot$ s$^{-1}$ at zero crossing on the interpersonal distance axis, during an unsuccessful tackle when an attacker passed a defender. Figure 3c shows a continuous increase in relative velocity within 4 m of interpersonal distance to above a value of 3 m $\cdot$ s$^{-1}$. There followed a sudden decrease in relative velocity to below 2 m $\cdot$ s$^{-1}$, when a successful tackle destabilized system dynamics.

**Discussion**

In this study, a comparative analysis was used to examine the relative utility of two potential control parameters in rugby union dyads: interpersonal distance and attacker–defender relative velocity. Data from previous work on attacker–defender dyads suggested that, with decreasing interpersonal distance, a phase transition in dyadic organization might occur (Passos et al., 2006). However, the findings of this comparison showed that this potential control parameter did not contain sufficient information to drive a dyadic attacker–defender system in rugby union to one of the three possible coordination
patterns (Figure 1). In other words, interpersonal distance as a single control parameter could not explain the emergence of dyadic outcomes such as a try or an effective tackle. The results suggested that under the task constraints of rugby union (where physical contact between players is allowed according to the rules of the game), interpersonal distance can act as an *initial* potential control parameter that moves the dyadic attacker–defender system towards a region of self-organizing criticality. In this region, initial system organization was destroyed, with one of the three coordination patterns emerging – that is, a clean try, a tackle but the attacker passes the defender, or an effective tackle (see Bak, 1996; Kauffman, 1993; Van Orden, Holden, & Turvey, 2003). As elaborated upon later, it was within this region of self-organizing criticality that changes in the value of relative velocity created specific information (i.e. through the increasing or decreasing speed of the opponent) that constrained dyadic system behaviour.

The relevance of relative velocity as another potential control parameter in rugby union dyads can be observed between the vertical black dashed lines of Figure 2. In the time recorded between these dashed lines (in Figure 2a–c represented by a decrease in interpersonal distance), the moment when an attacker decided to run forward and pass a defender can be identified. During a clean try (Figure 2a), it can be observed that, at approximately 3.5 m of interpersonal distance, the attacker’s velocity increased, while that of the defender decreased. This differential produced a change in the players’ relative velocity that could be critical to the final outcome of pattern-forming dynamics in dyadic attacker–defender interactions. In contrast, during both tackle scenarios, it can be observed that, at the moment when the attacker decided to move past the defender – close to 2.4 m of interpersonal distance during an unsuccessful tackle (Figure 2b) and near 2.3 m of interpersonal distance during a successful tackle (see Figure 2c) – the attacker’s velocity was decreasing while that of the defender was increasing. These observations show that in both tackle scenarios, the defender was able to counterbalance the attacker’s actions and prevent the attacker from destabilizing the dyadic system.

The results of this comparative analysis highlight that pattern-forming dynamics in attacker–defender dyads in rugby union, especially phase transitions, might be explained with reference to two potential, nested control parameters: interpersonal distance and relative velocity. Our analysis revealed the importance of the spatial area encompassing 4 m of interpersonal distance between an attacker and defender (see Figure 3). Outside this distance, the qualitative analysis of relative velocity did not reveal a clear pattern (i.e. relative velocity values displayed random fluctuations). These random fluctuations in relative velocity may have been due to exploratory decisions and actions (expressed as changes of running line direction and speed) of both players to maintain their goal-directed behaviour. Within approximately 4 m of interpersonal distance, affordances for actions – that is, possibilities for actions available in the performance environment (e.g. the space left available by a defender is an affordance to be explored by an attacker or a decrease in attacker velocity is an affordance for the defender to perform a tackle) – become restricted and the dyadic system evolves to a single solution that is expressed in one of the three possible coordination patterns of the system. From Figure 3a it can be observed that within 4 m of interpersonal distance, relative velocity increased (i.e. with the attacker moving position faster than the defender). The results show that, if these values increased or were maintained above 2 m \( \cdot s^{-1} \), the system evolved to a try being scored with no physical contact between players taking place. Alternatively, as displayed in Figure 3c, relative velocity increased within 4 m of interpersonal distance (i.e. the attacker increased velocity and the defender decreased velocity). However, the defender was able to counterbalance the attacker’s decisions and actions and the values of relative velocity suddenly decreased (i.e. when the defender velocity increased and the attacker velocity decreased), with the dyadic system evolving towards an effective tackle situation. Similar behaviour occurred for tackles where the attacker passed the defender (Figure 3b), typically with relative velocity consistently remaining below 2 m \( \cdot s^{-1} \).

These data highlight the nested interactions between the two potential control parameters. They support the existence of critical periods in the social interactions of dyadic attacker–defender systems. Critical periods have been defined as brief windows during which a system’s organization is most open to modification from external and internal influences (Anderson, 2002). The results of the present study suggest that in the dynamic social interactions of attacker–defender dyads, a critical period influencing the stability of such dyadic systems over short timescales (i.e. seconds or fractions of a second) emerged at around 4 m of interpersonal distance during which changes in relative velocity had strong effects on system organization.

Critical periods in attacker–defender interactions were encompassed in the region of self-organizing criticality where the dyadic system was more susceptible to the influence of constraints; that is, the attacker–defender system is more susceptible to internal and external influences that could change system organization. Indeed, our results suggest the
existence of two preferred zones (attractors) in the region of self-organizing criticality to which the dyadic system evolves (see Figure 4): (i) the “contact zone”, bounded by 4 m of interpersonal distance and below 2 m s\(^{-1}\) of relative velocity; and (ii) the “no-contact zone”, also bounded by 4 m of interpersonal distance, but above 2 m s\(^{-1}\) of relative velocity. Despite the huge variability of trajectories that each player might have undertaken, within the 4 m of interpersonal distance the attacker–defender system was always attracted to one of these “preferred” zones, the “contact” or the “no-contact” attractor zone. These attractors in the region of self-organizing criticality capture how the two candidate control parameters function in a nested manner to provide informational constraints on system dynamics. That is, relative velocity values, embedded within a particular interpersonal distance value, created a specific information flow that constrained the trajectory of an attacker–defender system to one of the three coordination patterns previously presented: (i) if relative velocity values increased, a try was scored; (ii) and (iii) if relative velocity values decreased below 2 m s\(^{-1}\), a tackle was made (successful or unsuccessful).

These outcomes from the data analysis can be interpreted in accordance with Juarrero’s (1999) insights as to how phase transitions can emerge in self-organizing systems. For example, in rugby union dyads phase transitions might occur due to changes in the nature of interactions between system components (e.g. non-physical interactions and physical contact between players of an attacker–defender dyad) or due to organizational changes in a dyadic system (due to changes in the players’ relative spatial proximity to the try line in rugby union). Juarrero’s (1999) proposals suggest that these changes in organization might lead a dyadic system in rugby union to one of three possible states: (i) physical contact occurs but the attacker does not pass the defender and initial system organization is conserved. However, the type of connection between the dyad components changes (from non-physical to physical), resulting in the system entering a new phase in the self-organizing, emergent process (Figure 1a). (ii) Physical contact occurs and the attacker passes the defender. Due to physical contact the type of connection between the dyad components changes. But the main difference between this new emergent state and the previous one is that there is a change in internal organization of the system (demonstrated by a zero crossing in interpersonal distance relative values), and the attacker is now the player closest to the try line (Figure 1b). (iii) The attacker passes the defender without physical contact and the connection between the two players remains non-physical (Figure 1c). However, the dyad undergoes a phase transition given that the players’ within-system structural organization changes with the attacker now being closer to the try line than the defender. This outcome is characterized by a zero crossing in relative interpersonal distances, and is different from the previous state because of the continuous decrease in relative values due to an increase in interpersonal distance.

These findings suggest that a decrease in interpersonal distance over time (Figure 1) can drive the dyadic attacker–defender system in rugby union towards a phase transition. In these dyadic systems, each trial began after the attacker touched the ball with his right foot, and finished when either a try was scored or when the attacker fell on the floor after being tackled by the defender. But data on interpersonal distance alone are not accurate enough to characterize the type of phase transition that might occur, leading the system to one of the three possible states (i.e. coordination patterns) outlined above. From a dynamical systems perspective, it appears that interpersonal distance is a variable that can influence system behaviour until a particular moment in time and space. Typically, this moment is consistent with interpersonal distance in an attacker–defender dyadic system reaching a value of 4 m, after which it seems that players’ relative velocity can exert a stronger influence on dyadic system behaviour.

Figure 5 summarizes the main conclusions regarding the predictive utility of interpersonal distance and relative velocity as potential control parameters in attacker–defender dyadic systems in rugby union.

An issue for future research concerns the potential differences in performance of young participants (i.e. under-12 age group rugby players) and adult players. Indeed, the many anthropometric, technical, and experiential differences between pre-pubertal and

Figure 4. Two preferred zones to where the dyadic system evolves. Clean try (black line); tackle but the attacker passes the defender (grey line); effective tackle (black dashed line).
Conclusions and practical implications

From the results of the present study, it can be concluded that interpersonal distance is a potential control parameter that leads an attacker–defender dyad to a phase transition. However, interpersonal distance does not act alone. The results demonstrate that attacker–defender system phase transitions in rugby union can be explained by the coupling of two potential, nested control parameters – interpersonal distance and relative velocity – with the former influencing the pattern-forming dynamics of dyadic system behaviour over time. From an applied perspective, our results highlight that the critical issue in improving young players’ decision making is to create a velocity differential that allows them to succeed in destabilizing an “unwanted” dyad with a marking defender (i.e. one player increases velocity while the other maintains or decreases running line velocity). This differential could be achieved by seeking changes in running line direction, increasing running speed or both. A critical period in the pattern-forming dynamics of attacker–defender interactions exists within 4 m of interpersonal distance. Within this period, attackers and defenders need to be trained in making decisions to stabilize or destabilize dyads depending on their role. To achieve this aim, training sessions in rugby union should include small exercises that simulate the 1 vs. 1 sub-phase of the game, reproducing the same task constraints (e.g. field dimensions) that young players face in competitive performance settings. Forcing players to satisfy specific task constraints imposed on them directs them to explore the playing environment for unique solutions to the problems created by opponents and the positioning of their own teammates (Passos, Araújo, Davids & Shuttleworth, 2008b).

When interpersonal distance reached a critical value of around 4 m, the system evolved towards a region of self-organizing criticality where affordances were reduced and a single solution emerged that was expressed in one of the three possible coordination patterns of the system. These results indicate how decision making might be conceptualized as an emergent process and exemplify how nested control parameters can act in concert to guide a dyadic system formed by an attacker and defender through different organizational states. An issue that warrants further investigation is the limited evidence that suggests that, between 4 and 2 m of interpersonal
distance, there was a change in the rate of growth of relative velocity values which could affect system stability. Further research is also needed to address decision making in dyadic systems under a variety of task constraints in sport to verify the existence of other potential nested control parameters.

**References**


