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Decision making behaviour in team sports: informational constraints and the dynamics of interpersonal coordination in rugby union

Dissertação apresentada com vista à obtenção do grau de Doutor no ramo de Motricidade Humana e na especialidade de Ciências do Desporto

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ABSTRACT

This thesis aimed to investigate informational variables that constrain the dynamics of interpersonal coordination underlying players' decision-making behaviour in team sports. We begin with a position paper highlighting the need for understanding how performers interact and generate goal-directed adaptive behaviours coupled to the information sources unfolding in the performance contexts. Thereafter, in all empirical studies performer-environment interactions are analysed with process-tracing methods to examine behaviours' dynamics. Relevant variables expressing players' behavioural interactions were identified and analysed in matches and rugby sub-phases (i.e., 1vs1, 1vs2, 3vs3). Analysis of the distance gained dynamics in attacking phases of actual matches revealed that ball displacement provides information on team successful performance. Besides, this variable dynamics described the functional coordination between players and teams. Using also actual match data, the functional role of gap closing information during 1vs1 sub-phases was analysed. Time-to-contact between attacker and defender was suggested as yielding information about future pass possibilities. In an *in situ* simulation of 1vs2 sub-phase, the manipulation of the initial distance between defenders demonstrated that decision-making behaviours are differently expressed as a function of changes made in participants' spatial location. This gave evidence for the flexible and adaptive nature of players' goal-directed behaviour to current task constraints. Finally, observations of participants performing a virtual reality simulation of 3vs3 sub-phase revealed how opening of gaps in the defensive line shapes decision-making behaviour of the ball-carrier. An expertise effect was demonstrated for perceiving and acting upon affordances. In conclusion, this body of research found that decision-making behaviour emerges sustained by specific spatial-temporal information from goal-directed interactions between players.

Keywords: Decision-making; perception-action coupling; affordances; information; interpersonal coordination; goal-directed behaviour; constraints; expertise; team sports; rugby union.

RESUMO

Esta tese teve como objectivo investigar variáveis informacionais que constrangem a dinâmica da coordenação interpessoal subjacente ao comportamento decisional dos jogadores em desportos de equipa. Começamos com um artigo de opinião enfatizando a necessidade de se compreender como os atletas interagem e geram comportamentos intencionais e adaptativos acoplados a fontes de informação presentes nos contextos de performance. Em todos os estudos empíricos que se seguem, são analisadas interacções atleta-envolvimento com métodos de seguimento do processo para examinar a dinâmica do comportamento. Foram identificadas e analisadas variáveis relevantes expressando as interacções comportamentais dos jogadores em jogos e subfases de rugby (i.e., 1x1, 1x2, 3x3). Análise da dinâmica da "distância ganha" em fases de ataque do jogo formal revelou que o deslocamento da bola fornece informação sobre o desempenho de sucesso das equipas. A dinâmica desta variável manifestou-se também caracterizadora da coordenação funcional entre jogadores e equipas. Utilizando ainda dados recolhidos em jogo, foi analisado o papel funcional da informação proveniente de espaços em encerramento durante subfases de 1x1. O tempo-para-contacto entre atacante e defesa foi sugerido como contendo informação sobre possibilidades de passe. Numa simulação *in situ* de subfases de 1x2, a manipulação da distância inicial entre defesas demonstrou que os comportamentos decisionais são expressos distintamente em função de mudanças efectuadas nas localizações espaciais dos participantes. Isto forneceu evidência da natureza flexível e adaptativa do comportamento intencional dos jogadores em relação aos constrangimentos da tarefa presentes. Finalmente, a observação de jogadores a desempenhar uma subfase de 3x3 virtualmente simulada relevaram que espaços que surgem na linha defensiva moldam o comportamento decisional do jogador com bola. Um efeito de perícia foi demonstrado para a percepção e acção sobre affordances. Em conclusão, este corpo de investigação verificou que o comportamento decisional emerge de informação espácio-temporal específica que resulta das interacções intencionais entre jogadores.

Palavras-chave: tomada de decisão; acoplamento percepção-acção; affordances; informação; coordenação interpessoal; comportamento intencional; constrangimentos; perícia; desportos de equipa; rugby XV.

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Contents

1. Introduction 2

1.1. Thesis underlying framework: Ecological Dynamics Approach 2

1.2. Outline of the present thesis: A Preview 6

1.3. References 8

2. From recording discrete actions to studying goal-directed behaviours in team sports 14

2.1. Abstract 14

2.2. Introduction 15

2.3. Manipulation of information during performance influences emergent actions 15

2.4. Individual or collective performance in sport is traditionally defined by recording discrete actions 17

2.5. Performers' interactions express goal-directed behaviours to satisfy performance constraints 19

2.6. Decisions are expressed by ongoing and goal-directed player-environment (inter)actions 20

2.7. Acknowledgments 22

2.8. References 22

3. Territorial gain dynamics regulates success in attacking sub-phases of team sports 26

3.1. Abstract 26

3.2. Introduction 27

3.2.1. Dynamics of Territorial Advantage in Rugby Union Second Phases-of-play 29

3.3. Method 30

3.3.1. Sample 30

3.3.2. Recording Procedures 31

3.3.3. Data Inclusion/Exclusion Criteria 31

3.3.4. Grouping Successful and Unsuccessful Situations 32

3.3.5. Data Processing 33

3.4. Results 35

3.4.1. Distance Gained Behaviour 35

3.4.2. Maximum Distance of Retreat 36

3.4.3. Territorial Gain Dynamics 38

3.4.4. Variability of Distance Gained Time Series 38

3.5. Discussion 40

3.5.1. Distance Gained Behaviour 41

3.5.2. Phase-of-play Dynamic Behaviour Distinguishing Success in Territorial Gain 41

3.4.4. Variability of Distance Gained Depicting Success in Territorial Gain 42

3.5.4. Collective Behaviour Conveyed by Distance Gained Dynamics 43

3.6. Acknowledgments 45

3.7. References 45

4. Prospective Information for Pass Decisional Behaviour in Rugby Union 50

4.1. Abstract 50

4.2. Introduction 51

4.2.1. Prospective information unfolding players–environment interaction and decisional behavior 52

4.3. Methods 55

4.3.1. Data/sample 55

4.3.2. Variables 56

4.3.2.1. Approach variables (candidate informational variables) 57

4.3.2.2. Pass variables (action variables) 57

4.3.3. Data analysis 58

4.4. Results 60

4.4.1. Distance motion gap 60

4.4.2. Informational variables and pass variables 60

4.4.3. Inter and intra-trial tau variability 61

4.5. Discussion 63

4.5.1. Information that influences pass behavior 64

4.5.2. Tau inter-trial variability 66

4.5.3. Attacker–defender dyad constraints and the detection of pass affordance 67

4.6. Acknowledgment 70

4.7. References 70

5. Changes in practice task constraints shape decision-making behaviours of team games players 74

5.1. Abstract 74

5.2. Introduction 75

5.3. Method 76

5.4. Results 79

5.5. Discussion 82

5.6. Conclusion 84

5.7. Practical Implications 85

5.8. Acknowledgments 85

5.9. References 86

6. Perceiving and acting upon spaces in a VR rugby task: expertise effects in affordance detection and task achievement 90

6.1. Abstract 90

6.2. Introduction 91

6.3. Methods 92

6.3.1. Participants 92

6.3.2. Task 93

6.3.3. Design and procedure 95

6.4. Results *97*
6.4.1. Action Performed 97
6.4.1.1. Gap location effects in the Action performed 97
6.4.1.2. Expertise effects on the Action performed 98
6.4.1.3. Gap and Expertise Interaction effects on the Action performed 99
6.4.2. Task achievement 100
6.4.2.1. Gap effects on Task achievement 101
6.4.2.2. Expertise effects on Task achievement 101
6.4.2.3. Gap and Expertise Interaction effects on Task achievement 102
6.5. Discussion *102*
6.5.2. Different Gap locations offered different actions independently of participants' expertise level 102
6.5.2. Rugby expertise effects in selecting the action for task achievement 103
6.6. Acknowledgments *105*
6.7. References *106*

7. General Discussion 110

7.1. Overview of main findings *110*
7.2. Methodological considerations *112*
7.3. Theoretical implications *113*
7.4. Future research *115*
7.5. Practical implications *116*
7.6. Concluding Remark *118*
7.7. References *119*

Figures

Figures were numbered following chapter number.

Figure 3.1. Original game scene taken by the camera. Demarcation of the variable distance gained and the respective lines considered for its computation (illustrative scene). 31

Figure 3.2. Distance gained as function of normalized time for randomly selected exemplar data: (a) two illustrative successful trials; and (b) one illustrative unsuccessful and one illustrative successful trial.....36

Figure 3.3. Maximum distance of retreat achieved as a function of normalized time for the entire sample trials (square marks) and classification line (dashed line) from linear discriminant analysis (LDA)..........37

Figure 3.4. Two-dimensional phase plot of the distance gained d of the time series (on the horizontal axis) versus the first derivate *D'* (on the vertical axis) for the entire sample of successful and unsuccessful trials. 38

Figure 3.5. Autocorrelation of distance gained time series for success and unsuccessful illustrative trials (.04-s lags). 39

……

Figure 4.1. A schematic representation of pass distance and angle in a second phase-of-play. 58

Figure 4.2. Distance between the first receiver (with ball) and the marking defender over time for all the analyzed trials (n = 13). 60

Figure 4.3. Dispersion diagram of pass duration (dependent variable) as a function of the initial tau value (independent or predictive variable)...61

Figure 4.4. Point-by-point tau average band (M ± SD) of the distance motion gap between the 1st receiver and the defender (James, 2004) for all the analyzed trials (n = 13). X = 0 marks the instance the 1st receiver receives the ball from the onset of the second phase-of-play, i.e., the beginning of the part of the approach ‘‘with the ball’’. 62

Figure 4.5. Tau dynamics over the last 18 data points of the period of approach ‘‘without ball’’ and the first 12 data points of the period of approach ‘‘with ball’’. X = 0 marks the instance the first receiver receives the ball from the onset of the second phase-of-play, i.e., the beginning of the part of the approach ‘‘with ball’’. Examples are taken from situation 6 and situation 10. 63

……

Figure 5.1. A schematic representation of the 1 vs 2 experimental task. Outlined is the manipulated starting distance between defenders (distance defender 1 – defender 2). 78

Figure 5.2. Trials outcome histogram – try or tackle – over each value of the scaled starting distance between defenders. The bars value (vertical axis) determines the percentage (%) of occurrence. The categories (horizontal axis) concern the distance from which the defenders started the task in the correspondent sequence of change. 80

Figure 5.3. A (upper panel): exemplar trials of participants’ displacement trajectories in the two extreme values of the manipulated starting distance between defenders. Left panel is a trial performed with the greatest value (i.e., 20 meters) and in the right panel a trial performed with the smallest value (i.e., 2

meters) of the manipulated distance. B (middle panel): Mean and standard deviation of speed of participants' displacement trajectories for the decreasing values of the starting distance between defenders, for all trials. C (lower panel): Mean and standard deviation of the time period between first crossover and the end of the trial for the decreasing values of the starting distance between defenders, for all trials..82

………......

Figure 6.1. The immersive interactive virtual reality apparatus. The panel on the left shows a participant wearing the head mounted display (hmd) with attached head tracker along with the back pack that housed the control unit. The players also wore a pair of rugby gloves onto which two hand trackers were attached. Panel A illustrates what the players could see in front of them (i.e., the defensive line) and panel B shows what they could see if they turned their head to the left or the right (i.e., the position of their teammates (first and second receivers). 95

Figure 6.2. Scheme of gap conditions. Each gap location is defined by varying the running angle of the defender in a specific running channel. Gap 1: located in participant's own running channel. Gap 2: located in the running channel of the first receiver. Gap 3: located in the running channel of the second receiver...96

Figure 6.3. Panel A shows gap location broken down as a function of the three possible actions: run, short or long pass. Panel B shows how the distribution of action choices (run, short or long pass) varied between groups. * $p < .05$. ** $p < .001$ 99

Figure 6.4. The two panels show each defensive gap location broken down as a function of the three possible actions. Panel A: Gap 1 corresponds to a gap opening in ball-carrier's own running channel; Panel B: Gap 2 corresponds to a gap opening in the first receiver's running channel; Panel C: Gap 3 corresponds to a gap opening in the second receiver's running channel; Panel D: No Gap corresponds to the condition where no gap opens. * $p < .05$. ** $p < .001$. 100

Figure 6.5. A: Gap location main effects. The percentages of task achievement (assumed as the frequency of the expected action) broken down as a function of the opening gap locations. Gap 1 corresponds to gaps opening in ball-carrier's own running channel; Gap 2 corresponds to gaps opening in the first receiver's running channel; Gap 3 corresponds to gaps opening in the second receiver's running channel. B: Group main effects. Percentages of task achievement (assumed as the frequency of the expected action possibility) broken down as a function of each group of participants: non-rugby players, recreational, intermediate and professional rugby players...101

Tables

Tables were numbered following chapter number.

Table 6.1. *Effects of a multivariate analysis of variance (MANOVA).*..98

Chapter 1

General Introduction

1. Introduction

Team ball sports are activities in which a group of players interact simultaneously towards shared and opposing performance goals. That is, the attacking team (the team in the possession of the ball) aims to score points whereas the defending team aims to prevent the later from scoring and to regain possession of the ball. Throughout a match, players' decisions and actions are constrained by many variables (e.g., fatigue, other players' actions, grass characteristics, public buzzing). These multiple constraints are in turn responsible for multiple effects in both interpersonal interaction processes and outcomes (Passos, 2010). Besides, players within teams interact constantly, co-adapting towards goal achievement (Marsh, Richardson, Baron, & Schmidt, 2006; Passos, Milho, Fonseca et al., 2011).

In rugby union each team, made up of fifteen players, attempts to score points by kicking the ball within the goal posts or touching the ball down in the opposition goal area. To accomplish these performance goals, players must essentially advance the ball by running with it, passing or kicking the ball. However, they never face identical game situations, thus players' action solutions are not identical. Though there are a great number of moves that are pre-planned (i.e., strategic moves), it is acknowledged that players need to behave adaptively to the ever-changing situations of the game. It is straightforwardly observed in the game that rather than merely detained in pre-established action sequences – that coaches expect the players to carry out while performing – players' decisions and actions are emergent in their interaction with the performance environment. As follows, relevant questions are: *how players' and teams' decision-making behaviour emerges and changes over time? what constrains it? and, what is the role of information in this process?*

1.1. Thesis underlying framework: Ecological Dynamics Approach

The ecological dynamics approach to decision-making (Araújo, Davids, & Hristovski, 2006; Davids & Araújo, 2010) is grounded on postulations, concepts and tools from ecological psychology (Gibson, 1979) and nonlinear dynamics (e.g., Kugler, Kelso, & Turvey, 1980, 1982). The current thesis holds this ecological dynamics perspective while investigating decision-making behaviour in team sports, focusing on the informational constraints and the dynamics of interpersonal coordination in rugby union. As the main framework underlying the upcoming chapters, it imports to introduce a brief overview of the ecological dynamics approach, provide some of its key concepts and briefly describe how decision-making in sports are regarded throughout this thesis.

In ecological psychology, Gibson's (1979) theory of *direct perception* advocates that individuals can perceive directly the world as it is and mainly what they can do within it. This approach countered the perspectives on perception that regarded the properties of the world as ambiguously specified, impoverished and needing to be mediated by internal representations (e.g., Schmidt & Lee, 2005; Shaw, 2003). Gibson rejected these assumptions and argued that the input for perception can be accessed directly through patterns of the surrounding energy flows (e.g., optic flow) that specify unambiguously properties of the environment. Another assumption of ecological approach is the need for considering the reciprocity between *perception and action*, as the recurring well-known sentence of Gibson (1979, p. 223) reveals "we must perceive in order to move, but we must also move in order to perceive". Besides, rather than merely reacting to what happens, action is dynamically controlled ahead of time by picking up relevant prospective information (e.g., Gibson & Pick, 2000; Reed, 1996; Turvey, 1992). Consistent with the ecological approach, David Lee and followers (e.g., Bastin, Craig, & Montagne, 2006; Craig, Goulon, Berton, Rao, Fernandez, & Bootsma, 2009; Bootsma & Craig, 2003; Lee, 1998) argued that goal-directed movement is future-oriented to functionally reduce the 'space' between current and goal states, i.e., entails the prospective guidance of the closure of motion gaps (i.e., any gap between measurable current and goal states).

The mutuality and reciprocity of the *perceiver and its environment* is also a key argument of this perspective. That is, though not disregarding organismic constraints (e.g., preferences, fatigue, eye movements) the emphasis rather than placed solely in the individual, or solely in the environment, is instead in the relation between these (Araújo, Davids, Cordovil, et al., 2009). Importantly, Gibson put also forward that human behaviour rests on the perception of *affordances*, or opportunities for action. These are tendered by the environmental properties by taking each organism's body dimensions or action capabilities (aka effectivities) (e.g., Mark, 1987; Oudejans, Michaels, Bakker, & Dolné, 1996; Turvey & Shaw, 1999; Warren, 1984).

The ecological dynamics approach to decision-making in sports (Araújo et al., 2006) advocates likewise the *perception-action coupling* and *individual-environment* continuous relationship to understand how humans' perception, cognition, decision-making and action emerge. It contests also the perspectives that regard behaviour as supported on a central controller, a scheme or mental model with organization and control roles (Davids & Araújo, 2010). Ecological dynamics considers *goal-directed behaviour* as emergent from *interactions* amongst players in the dynamic environments of performance (Araújo et al., 2006; Davids & Araújo, 2010). Goal-directed behavior is not owned by each player, neither controlled by external factors (e.g., the coach's call for a pre-established move), but rather a relational property arising from the interaction between players and the environment of performance, and shaped by the information surrounding and evolving in it. As follows, emergent *decision-making* has been conceptually defined as expressed behaviourally by *transitions in players' action paths* (Araújo et al., 2009; Araújo et al., 2006). Furthermore, players' action is guided by information. Decision-making comes about by environment exploration and detection of action possibilities (affordances) unique for each player and current performance goals (e.g., Araújo, 2010; Withagen & van der Kamp, 2010). Besides, either as opposing players or teammates, players tend to coordinate their behaviour towards goal achievement (McGarry, Anderson, Wallace, Hughes, & Franks, 2002). The emerging interpersonal coordination patterns are thus functional spatiotemporal orders, or adaptations, to changing circumstances (Araújo et al., 2006; Kelso, 1995; Kelso, 2002; Warren, 2006). Consistent with this, a growing body of research on sport performance concerns interpersonal interactions phenomena (e.g., Araújo, Davids, Bennett, Button, & Chapman, 2004; Davids, Button, Araújo, Renshaw, & Hristovski, 2006; Davids, Button, & Bennett, 2008; Passos, Araújo, Davids, Gouveia, Milho, & Serpa, 2008; Passos, Araújo, Davids, Gouveia, & Serpa, 2006). Interpersonal coordination patterns emerge from these interactions during performance, shaped by contextual, individual, and task constraints (Araújo et al., 2004; McGarry & Franks, 2007; Passos et al. 2008). Constraints on behaviour, such as task manipulated constraints, may thus change the way information is used by individuals (Jacobs & Michaels, 2007; Jacobs, Runeson, & Michaels, 2001). Therefore it is essential to bear in mind whether the experimental task constraints designed to investigate a certain perception-action coupling in sports correspond to those of the actual context for which the experimental findings are expected to hand understanding. Ecological dynamics extends Gibson's approach also by emphasizing the concept of *representative design* (put forward by Brunswik, 1956; see also Hammond & Stewart, 2001). This conception shields that experimental task constraints representative from the context for which it is intended to be generalized are essential to those who aim to investigate decision-making behaviour in sports but also for the design of training and learning tasks meant to improve players' and teams' performance (Araújo et al., 2006; Davids, 2008; Davids, Araújo, Button, & Renshaw, 2007; Pinder, Davids, Renshaw, & Araújo, 2011). This consideration in the design of experimental task constraints emphasizes the functionality of behaviour, as modifications in these constraints were empirically demonstrated to influence substantial behavioural changes (e.g., Hristovski, Davids, Araújo, & Button, 2006). Investigation carried out in this thesis complies with these representative design concerns.

Identifying these interpersonal coordination patterns, what constraints shape them, and to what information players attend during performance, is held by ecological dynamics approach as assisting the better understanding of the mechanisms underlying decision-making in sports (Araújo et al., 2006). The current thesis considers the goal-directed interactions between rugby union players and their performance environment (such as other players), and the ensuing performance outcomes, aiming to investigate: pattern forming dynamics of players' decision-making behaviour over time; potential variables conveying the dynamics of this functional organization among interacting players; how individual players constrain and are constrained by the actions of other players; how goal-directed action may be updated constantly and ahead of time, i.e., what potential prospective information shapes players' decision-making behaviour; how contextual constraints (e.g., task constraints) change the way that information is used by players and shape emergent decision-making; and how this information detection and use differs between performers of varying levels of rugby union expertise.

1.2. Outline of the present thesis: A Preview

The present thesis embraces a collection of 5 articles (1 review article and 4 research articles) published, in press, under review, or submitted for publication in peer-review journals with ISI Impact Factor. Like this, each chapter is presented as an individual article following the format requested by the journal of submission/publication in respect to its sections (i.e., abstract, introduction, methods, results, discussion and references), reference style, figures, tables and captures.

The overall purpose of this thesis was to investigate decision-making behaviour in team sports. Though particularly applied to rugby union game, the studies embraced shed light to the understanding of informational constraints and dynamics of interpersonal coordination of any team sports, abiding evidently the particularities of each.

The studies involved in this PhD have focused on the analysis of players' decision-making behaviour in different rugby performance contexts. We have carried out both *in situ* (actual match or representative sport tasks) and lab experiments (i.e., virtual reality setting). The obtained data was mainly of kinematic time series nature from which it was possible to investigate relevant variables of the system under analysis (either at team or sub-phase level) and to relate their dynamics with the emergent behaviour dynamics of players and teams towards goal achievement.

Although ecological researchers hold that players' action entails a relationship between information and action, the overall investigation of decision-making in sports has regarded players as discrete actors rather than on the changing information guiding the on-going goal-directed interactions of players with the environment. Accordingly, Chapter 2 contributes theoretically to the topic of decision-making behaviour in sport. It comprises an opinion article (**"From recording discrete actions to studying goal-directed behaviours in team sports"**) aimed to present an illustrative overview on how decision-making in team sports has been investigated. It aims particularly to outline the discrete focus of traditional research and argue for the need to attend to the continuous and inter-dependent goal-directed interaction guided by information unfolding in the performance environment.

Under the research studies taken *in situ*, the study presented in Chapter 3 (**"Territorial gain dynamics regulates success in attacking sub-phases of team**

sports"), holding no manipulation and thus embracing a descriptive character, aimed to identify the collective system dynamics of rugby union phases-of-play by investigating whether ball displacement data on the playing field near the try line provides information on successful team performance.

Still beneath the *in situ* umbrella, the study shown in Chapter 4 (**"Prospective Information for Pass Decisional Behaviour in Rugby Union"**), thought still with no manipulation, purposed to empirically assess whether players' decision-making behaviour about which type of pass to make is influenced by the informational spatiotemporal variable tau (or time-to-contact) unfolding approaching players (i.e., the player that makes the pass and his marking defender).

Considering that interpersonal coordination is highly dependent on local constraints, the study presented in Chapter 5 (**"Changes in task constraints shape decision-making behaviours of team games players"**) involved manipulation *in situ* of task constraints. This study aimed to investigate the influence of manipulating the defenders' initial positioning to study emergent decision-making behaviours in a one-versus-two rugby sub-phase.

In Chapter 6 we stepped into a more controlled experimental setting. Carried out using an immersive and interactive virtual reality (VR) rugby environment, the study presented here (***"*Perceiving and acting upon spaces in a VR rugby task: expertise effects in affordance detection and task achievement"**) aimed to investigate how gaps closing in specific running channels shapes ball-carrier's actions (i.e., affords particular actions). We aimed also to demonstrate the progressive rugby expertise in terms of achievement in this task of detecting and acting upon spaces in a 3vs.3 game sub-phase.

Finally, in Chapter 7 (**General Discussion**) the main findings from the experiments presented in this thesis are outlined and discussed within the ecological dynamics framework. In addition, considerations regarding the methodological steps taken throughout these experiments are presented. Subsequently, the overall theoretical implications from this thesis are drawn and some notes for future research are presented. This chapter ends addressing potential practical implications from this thesis.

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Chapter 2

From recording discrete actions to studying goal-directed behaviours in team sports [1]

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2. From recording discrete actions to studying goal-directed behaviours in team sports

2.1. Abstract

Objectives: This paper aims to theoretically integrate empirical findings and methodological approaches of two predominantly disparate programmes of research in sport science, despite studying the same phenomenon - behaviour in sport. These programmes are performance analysis and the study of expertise in the sport psychology literature. Design and Methods: With reference to data from illustrative studies, we critically evaluate some of the main assumptions and methodological characteristics in these research programmes. Results: Our analysis revealed that performance analysis research and studies of sport expertise are typically centred on production of discrete actions by individual performers. We propose how the focus on decision-making behaviours and action in team sports may be enhanced if re-directed to study ongoing interactions of performers and their environments and on the information used to continuously guide their goal-directed behaviours. Conclusion: We discuss ecological dynamics as a potential unifying theoretical framework to achieve this re-directed focus in future research.

Keywords: decision-making; information; action; interpersonal interactions.

2.2. Introduction

In team sports, athletes are the key actors in a dynamic performance environment continuously interacting with each other to achieve performance goals which are mutually exclusive between opposing teams. While the attacking team (team in possession of the ball) aims to score (e.g., a try in rugby union or a goal in soccer), the defending team aims to prevent the attacking team from scoring and to regain possession of the ball. Decision-making in sport is a continuous process grounded on an individual's perception and action capabilities and in the information needed for action selection and goal achievement [1].

In the literature research exists: (i) querying how *information* is used by performers of different expertise levels in team sports, (ii) examining *what actions* are performed in competitive performance and assessing discrete measures of behaviour commonly related with performance outcome measures, and (iii), focusing on the *interaction of performers* with the performance environment (and its specific ecological constraints) and in the physical variables underlying deciding and acting. In these research programmes, there is a need for more work to understand how performers interact and create goal-directed adaptive behaviours coupled to the many and dynamic information sources in performance contexts. In this paper we outline this paucity in research and provide some illustrative empirical evidence emerging from studies of team sports. We draw attention to the implications of the contemporary overemphasis on analysing discrete actions performed by individual athletes and provide a rationale for developing further research programmes investigating interpersonal interactions/collective activities of team sports performers.

2.3. Manipulation of information during performance influences emergent actions

A particular focus of the sport expertise research has been on what discrete 'cues' may be used by individuals for effective performance. For example, recent research claimed to demonstrate how schemata or action rules (basketball and handball [2]) and information processing and memory interface processes (association football [3]) allowed participants to plan and program movements before performing. The information made available to participants in these studies consisted of hypothetical and static images depicting game states. For example, this information was provided in hard copy form outlining attributes such as numerical status in performance sub-phases [2] or as images presented on a computer screen [3]. Participants were asked to verbally report what game strategy was appropriate or to press a computer keyboard corresponding to an action they would undertake.

In research on visual perception in sport, temporal and/or spatial occlusion paradigms, and eye movement registration techniques (for a review see e.g., Williams and Ericsson [4]), have been utilised in experimental settings. Temporal occlusion methods occlude filmed action sequences at determined time periods, requiring participants to report what would happen next, usually involving a discrete action (e.g., a button press) to choose between alternatives. This research has demonstrated, for example, that experts outperform novices, being able to detect 'cues' at an earlier time-point in an action sequence [5]. Spatial occlusion methods omit information components during the preparation and execution of an action image displayed on a screen [4], examining how this loss of information affects perception and decision-making efficacy. Eye movement registration techniques purport to assess the specific locations on an image where participants are fixating, also analysing temporal information such as fixation durations. With these techniques, discrete eye movement measures such as search rate, latency of saccade, fixation location, number of fixations, and fixation order, are reported as indicators of how sources of information are picked up by participants used to make judgments about actions. For example, Vaeyens and colleagues [6] combined visual gaze and occlusion analysis to investigate the relations between visual search behaviours, decision-making, skill and experience level in sport. Participants were presented with near life-size images in filmed sequences of different patterns of play in association football and asked to simulate a response by passing the ball at an image of a player on a screen, kicking the ball towards a goal, or moving as if to dribble past a defender. Decision-making processes were measured by establishing movement initiation time (gained from pressure-sensitive mats) and response accuracy (rated by expert coaches). Results led the investigators to assume that the cognitive knowledge basis of skilled participants helped them to pick up and interpret perceptual information more effectively than less skilled participants. The knowledge is in this way centred in the individual rather than in the relation between him/her, the task to be performed, and the environment of performance.

Virtual reality has been also exploited to investigate information used for perceptual judgments and actions. For instance, it has revealed evidence of spatiotemporal optical invariants as information influencing association football players' judgments (by button press [7]) and actions (hand movements in the direction of a ball [8]) on the trajectory of virtual simulated curved free kicks. Combining virtual reality with the temporal occlusion technique, Watson and colleagues [9] studied novice performers as they decided whether or not they could pass between two approaching defenders. The aim was also to understand which spatiotemporal information sources from the closing gap could prospectively support participant judgments (by button press) about the opportunities for passing/breaking the defensive line.

In summary, although there have been some investigations conducted in actual performance contexts, the most typical experimental approach has been to study participant behaviours under relatively artificial task constraints, manipulate the information available in these settings, and to relate these manipulations to task performance outcomes. Actions are sometimes taken into account, but performance outcome measures representing task achievement are almost always discrete (e.g., response time, response accuracy, response consistency). The focus is on the actor using discrete 'cues' to carry out discrete actions or provide reported judgments on possible actions. Importantly, with a few exceptions [8], most studies have attended to where and when athletes detect 'cues', but there is little systematic research about how performers *use* information throughout the course of action in goal-directed behaviour.

2.4. Individual or collective performance in sport is traditionally defined by recording discrete actions

Team sports performance has been analysed by seeking to record the type of actions that are performed in a competitive game. Discrete measures of action (e.g., amount of ball possession; number of accurate passes; number of tackles), whether considered over time (as in sequential analysis studies) or not (as in notational analysis), have been notated to describe successful or unsuccessful behaviours in performance contexts. Successful performance in sport has been commonly operationalized by recording data on discrete events or action indicators (e.g., goals, winners, errors, turnovers, tackles, passes/possession) [10].

For instance, point or goal scoring has been recognized as the most important event in team sports [11, 12]. In order to describe how goals were scored in association football, some investigators have analysed the 'style of play' by relating goal scoring data with passing sequences from matches [11]. Jones and colleagues [13] examined ball possession in football teams as a function of the evolving match status (i.e., winning, losing or drawing). Results showed that successful teams displayed significantly longer periods of ball possession than unsuccessful teams, but when match status was not considered, both groups displayed longer periods of possession when *losing* than when *winning*. Data from this study were interpreted as a consequence of differences in skill levels of individual teams instead of specific team strategies adopted.

Other research on match performance has focused on distinct aspects of performers' actions, either at an individual or team level, such as players' movement displacement trajectories during competitive performance [14, 15], patterns of events [16], occupation of different spatial areas of the field by individuals or teams [17], evolving match status [18], and effects of game venue on performance outcomes [13, 18].

In summary, this line of research has described decision-making performance by recording the patterned frequency of discrete actions in association with key events and constraints but has tended to neglect the study of the ecological conditions in which performance occurs. Particularly, there has been little attention paid to the information constraints of performance contexts that shape decision-making behaviours and how actions emerge from the continuous interactions between performers and the performance environment. The aim has typically been to identify *whic*h actions are performed, *who* performs them, and *when* those actions take place, defining individual or collective performance through isolated discrete variables, frequency counts or actions recorded in a sequential linear temporal scale. Current technological developments (such as the growing capability of different match analysis software packages and remote sensing technology) allow data collection and analysis of performers' actions in real time on a massive scale. Yet popular methods are limited to a discrete view of behaviour, rather than on the ongoing interactions of performers throughout competitive performance.

2.5. Performers' interactions express goal-directed behaviours to satisfy performance constraints

Team sports performance is predicated on interpersonal interactions of performers and teams as they act to satisfy spatial-temporal constraints of performance [19]. This approach focuses on identifying contextualised performance behaviours, regarding them as part of an adaptive and nonlinear changing process. A popular method for analysing contextualised performance involves the use of process-tracing methods (e.g., motion analysis), yielding time series data on physical spatial and temporal (relational) variables. These methods are commonly used to capture the course of action and its transitions during competitive performance. For instance, the spatiotemporal information sources identified in one of the previously mentioned studies using virtual reality [9] has also been recently investigated *in situ* [20] during competitive performance in a rugby union match with data obtained from motion analysis techniques. The findings confirmed the functional role of gap closing information during performer-environment interactions in 1vs1 sub-phases of competitive rugby union performance.

Also using process-tracing methods, Araújo and colleagues [21,22] showed that when a ball-carrier dribbled past a defender in 1vs1 sub-phases of basketball, a system phase transition occurred (quantified by an abrupt change in a physical measure: players' distance to the basket) and a new behavioural pattern emerged. In rugby union it has been demonstrated that the collective behaviours of attacker-defender dyads could also be defined by the dynamics of a physical relational variable: an angle defining the relative positioning of a defender and an attacker referenced to the try line [23]. In that study, data verified that the relative velocity of the ball-carrier and a marking defender, nested within a specific value for the interpersonal distance between the performers, indicated the critical threshold beyond which a phase transition in the course of action could occur [24] (for similar findings in association football see Duarte et al. [25]). In basketball, Esteves and colleagues [26], investigated decision-making of performers regarding direction of the drive towards the basket.

Their results demonstrated that the goal-directed behaviour of a ball-carrier was constrained by the posture of a marking defender, scaled to an intrinsic metric of the attacker-defender system, i.e., the drive emerged at particular interpersonal distance values between these players. This finding was consistent with the results of the previous studies, suggesting that interpersonal distance during ongoing interactions between attackers and defenders is a key performance constraint in 1vs1 sub-phases of team sports.

In summary, in the programme of work discussed here, the relations between the perception of information and action are regarded as crucial for understanding the underlying processes of decision-making in team sports. The research designs highlighted aimed to assess how performers adapt their actions, according to their own action capabilities and performance goals, to explore and detect what actions are possible in their unfolding interactions with key aspects of the performance environment (including key events, significant others and spatial locations of the playing area). Performer-environment interactions are analysed with process-tracing methods to examine the dynamics of performance behaviours, their transitions, and their relation with performance efficacy [23, 24, 25, 26].

2.6. Decisions are expressed by ongoing and goal-directed player-environment (inter)actions

To better understand decision-making and action in team sports, research should do more than simply record and describe the discrete actions or perceptual judgements made by participants isolated from their performance environments. An important task is: (i) to understand the information that performers detect from their performance environment in order to act; and (ii) how these information sources guide ongoing goal-directed performance behaviours [27]. However, in most prevalent methodological approaches in the literature, perception of information sources and actions are not considered as being linked. There is an asymmetric explanatory bias towards studying the “discrete actor” conceiving both processes as ‘actor-centred’, with their basis in organismic constraints [28, 29].

Traditional research on perception in sport focuses essentially on the discrete use of information for verbal judgments or micro-movements. Decision-making measures are recorded in a discrete fashion (i.e., discreet actions performed by individual athletes) and are often studied in isolation of sport performance contexts, and distinct from the relevant functional behaviours in those contexts (e.g., overemphasising the role of reaction time to a suddenly presented stimulus). Investigations rarely examine ongoing goal-directed interactions of participants with key performance constraints. For instance, visual occlusion research does not provide interpretation of what information is actually used in decision-making, given that occluded image areas, or the time of occlusion, are typically defined *a priori* by experimenters and limited to specific display areas. Participants may actually use variations of these experimenter-defined environmental properties. Gaze behaviour analysis also has some notable weaknesses, particularly concerned with the fact that an ocular fixation on a specific location of a visual display is not necessarily related to the use of that environmental property as a source of information for action [30]. Maintaining gaze in a particular region may involve 'visual anchoring' and the pick up of peripheral visual information.

Another area of concern is the generalization of results [19]. Although investigators have increased involvement of action in virtual reality simulation studies, they often still do not allow performers to undertake unhampered functional movement behaviours [31]. Different behaviours of participants have been reported when studied under simulation and *in situ* experimental task constraints [31].

An important consideration is how local interaction rules between players shape global system outcomes. The identification of relevant variables at a system (match) and subsystem (e.g., 1vs1 sub-phase) level that express the interactions between players and teams, and influence emergent decision behaviour, is most pertinent. This redirected focus to the functional player-environment continuous interaction should also consider how action patterns and action transitions reveal exploratory behaviours of players, i.e., decisions, to detect and create information about what actions are possible to achieve the performance goals. Furthermore, players and teams performance may be considered as being 'conditionally-coupled' [32]. That is to say that one discrete observation of an action variable at one point in time is dependent on previous observations of that variable, signifying that it should not be studied in isolation (as occurs in traditional teams performance research) to fully understand behaviour

In conclusion, although previous research has improved understanding of team sports performance, further work is needed to fully understand how excellence in performance emerges. It is most important to not just focus on specific information sources nor on discrete actions to describe successful performance. An important challenge is to investigate the dynamics of ongoing goal-directed (inter)actions of performers in sport, considering their context-dependency, and concurrently assessing what information is being used to support functional behaviours. An important empirical task is to seek ways to manipulate the information available in performance environments and verify the relation of these information sources with the ongoing dynamics of action, while avoiding a discrete and actor-centred perspective.

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Chapter 3

Territorial gain dynamics regulates success in attacking sub-phases of team sports [2]

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3. Territorial gain dynamics regulates success in attacking sub-phases of team sports

3.1. Abstract

Background and Objective: Field invasion games, such as rugby union, can be conceptualised as dynamic social systems in which the agents continuously interact to contest ball possession and territorial gain. Accordingly, this study aimed to identify the collective system dynamics of rugby union phases-of-play near the try line by investigating whether ball displacement trajectory on the playing field provides insights on successful team performance. **Method:** Five rugby union matches were videotaped involving teams at a national league performance level. From these matches, 22 second phases-of-play were selected and digitised for analysis. The variable “distance gained” was investigated as a potential coordination variable describing functional coordination between players and teams. This variable concerned the distance between ball initial position and ball current position over time and was used to define the degree of territory gained by an attacking team. **Results:** Analysis of distance gained dynamics in attacking sub-phases demonstrated the intermittent character of rugby union performer displacement trajectories on the playing field. Amplitude of ball movements was revealed as a distinguishing feature related to attacking effectiveness. Successful attacking phases displayed lower distances of positional retreat, with the maximum retreat distance achieved sooner in successful compared to unsuccessful phases-of-play. Autocorrelation and ApEn analyses suggested low system variability within time series data concerning both performance outcomes. However, evidence of less regularity and more complexity was found in unsuccessful phases-of-play. **Conclusion:** Results suggested that distance gained dynamics manifests a characteristic collective behaviour pattern that captures the macroscopic functional order of multi-player attack-defence systems in team sports like rugby union.

Keywords**:** pattern-forming dynamics, coordination variable, decision making, team sports.

3.2. Introduction

Field invasion games can be characterised as complex, social neurobiological systems in which agents interact continuously to contest ball possession and seek territorial advantage. In the team sport of rugby union, for example, Greenwood (2003) proposed that “possession is only a potential advantage” (p. 20). The team in possession of the ball strives to maintain continuity of possession and to advance up field and score points. Conversely, opponents contest ball possession, hamper displacement of players with the ball, and attempt to advance up field to reach a position advantageous for a potential counter-attack. Within these player-environment interactions, the balance of contestability and continuity, coordination and competition, coexist in a complementary way and are believed to be depicted in team’s displacement trajectory during performance. This perspective brings about the need to describe and explain the pattern forming dynamics of system agents over time (Passos, Araújo, Davids, & Shuttleworth, 2008). In rugby union, a chief task constraint on decision making and actions of players is the backward pass (International Rugby Board, 2010). Due to this task constraint of the game, negative team momentum (i.e., negative values of distance gained corresponding to a retreating movement of the ball) might be expected, hampering territorial gains by an attacking team. This influential rule of rugby union implies that the forward movement (territorial gain) of an attacking team is characterized by cycles of passing the ball, running with it to gain ground and being tackled. These cycles correspond to phases of play. A first phase-of-play or set play constitutes all restarts that follow a scrum, a lineout, a drop-out or a free kick. A second phase-of-play constitutes all open play “where the team controlling the ball will aim to ‘‘recycle’’ the ball after a tackle contact is made and a ruck/maul (breakdown) occurs” (Best, McIntosh & Savage, 2005, p. 816) (for a detailed description of game stoppages see the International Rugby Board manual, 2010). This study aimed to develop an understanding of collective decisional behaviour in the team sport of rugby union during attacking second phases-of-play. The specific objective was to understand whether the variable, distance gained, might convey the dynamics of decision making behaviours of attacking players during rugby union performance.

In social neurobiological systems such as team sports, patterns of behaviour emerge during performance from individual-environment goal-directed interactions (from 1-vs-1 to 15-vs-15 game sub-phases) and can be studied through attacker-defender symmetries and symmetry breakings, decisions and actions (Araújo, Davids, & Hristovski, 2006). Team sports can be regarded as social neurobiological systems in a complementary perspective that integrates each performer's central nervous system , body-environment interactions (biological – or interactions of a biological movement system and its environment) in an interpersonal social system (Davids, Araújo, Shuttleworth, & Button, 2003; Newell, 1986; Neisser, 1994; Keil, Holmes, Bennett, Davids, & Smith, 2000; Kelso, 2009; Van Gelder & Port, 1995). Social neurobiological systems are important to study because movement behaviour of each individual performer may be considered an emergent property of the continuous interactions of biological animated systems and the environment in goal directed behaviours (Newell, 1986; Davids, Araújo, Shuttleworth, & Button, 2003; Davids, Button, Araújo, Renshaw & Hristovski, 2006; Kelso, 2009). In social neurobiological systems, a relevant concept to understand is self-organization (Kelso, 1995, 2009). Self-organization implies that spatio-temporal patterns between system agents are not externally planned or organized by a coordinating agent according to a pre-existing template or a group internal representation, but rather are emergent from the non-linear interactions of the dynamic elements of the system (Schweitzer, 1997). As argued by Kelso (2009), emergent self-organizing dynamics in living systems (e.g., a team game), has its basis in information which is displayed through the parameters acting on the relevant variables of the system. Unlike inanimate systems, functional coordination underlies animated systems and within these systems information simultaneously acts and is originated from self-organizing processes (Kelso, 2009). Besides, functional coordination implies that agents in these systems exhibit a kind of spacio-temporal ordering that adapt in a flexible manner to varying circumstances (Kelso, 2002). An important variable which describes emergent, self-organized dynamic patterns in complex systems is the order parameter or collective variable (Kelso, 1995, 2009). Coordination variables are context-dependent and describe how patterns are formed and evolve across time in social neurobiological systems. They capture the functional organization among interacting elements and processes in space and time (Kelso, 2009). A coordination variable results from the cooperation between parts of a system and simultaneously constrains the behaviour of those individual parts (Kelso, 1995). In the performance context of competitive team sports, McGarry and colleagues (McGarry, Anderson, Wallace, Hughes, & Franks, 2002) have viewed this variable as a measure of the relationship between individual system components.

In the current study, performance in rugby union sub-phases of attackers and defenders was analysed to generalise towards collective decisional behaviours in team sports.

3.2.1. Dynamics of Territorial Advantage in Rugby Union Second Phases-of-play

Rugby union is a field invasion team game characterised by intermittent ('stop-go') patterns of play (e.g., Greenwood, 2003; Reed & Hughes, 2006). Between recurrent game stoppages, each team in possession of the ball aims to gain ground relative to an initial starting position. A projected line parallel to the try line that identifies a gained position (i.e., where the ball was regained from the opposite team) is labelled the gain line and is a reference to measure the degree of territory successfully gained in an attack (Bessa, 2005; Greenwood, 2003). Another important performance measure exists in the contact line. This is another projected line parallel to the try line that identifies the current position of the ball. Since in rugby union the ball-carrier can be stopped by defenders by being tackled to the ground, the ball's initial position ("gain line") assessed against its current position ("contact line") defines the degree of territory gained by an attacking team. In this study we have hypothesized that "contact line" movement over time could capture the functional ordering of attacking and defending player synergies in a phase of play of a rugby union match. Synergies at this juncture are understood as the functional alignment of players who are constrained to act as a single coherent sub-unit (cf. Kelso, 2009) coordinating and competing to assist common performance goals. As a candidate variable to capture interpersonal coordination of attacking players in this team sport we investigated the distance between the gain line and the contact line. We assumed that ball displacement trajectory on the playing field might yield information about success in attacking phases-of-play in a rugby union match. In a previous analysis of neurobiological system coordination, Vereijken and colleagues (Vereijken, van

Emmerik, Bongaardt, Beek, & Newell, 1997) analyzed the dynamics of a single variable (i.e., centre of mass) regarding it as an encompassing measure to reflect the global dynamics of motor system degrees of freedom during a dynamic balancing task. Using similar experimental logic, in the present study we assumed that distance gained might be a variable capable of capturing the collective actions of the agents (e.g., players) in social neurobiological systems exemplified by rugby union matches.

Our aim was to identify the collective dynamics of attack-defence sub-phases of play that, due to proximity to the try line, were assumed to precede the possibility of a try being scored. To achieve this aim, analysis of the pattern dynamics of ball displacement trajectory was undertaken within phases-of-play in which the attacking team was playing inside the opponent's half of the field. Specifically, the focus was on the dynamics of progression and retreat of the ball in the field within second phases-of-play of rugby union performance.

3.3. Method

3.3.1. Sample

We investigated twenty two attack-defence rugby union second phases-of-play near the try line ($M_{\text{distance to the try line}}$= 21.39; SD= 6.86 metres) recorded from five national rugby union senior league games (semi-finals and final of the Portuguese Rugby Union First League Championship 2007/08, and semi-final and final of the Portuguese Rugby Union Cup 2008). Data acquisition processes were compliant with the university institution ethical guidelines. Players taking part in these games, and in the phases-of-play considered for analysis, averaged 28 years of age (*M* = 27.75; SD = 4.03 years). The participant group was homogenous regarding rugby union playing experience (*M* = 17.5; SD = 4.69 years). It is important to note that, due to try line proximity, the performance situations were selected for analysis because they were considered to precede the possibility of a try being scored. Given that a try is scored only with the ball in hand, the greater proximity of the ball to the try line was assumed to reflect situations in which the attacking team was closer to achieve the performance goals. Being closer to opponents' in-goal area, players are like this closer to score whether by grounding the ball within this area (i.e., try) or by kicking (i.e., penalty try, conversion goal, penalty goal, or dropped goal; see IRB 2010 for detailed information).

A phase-of-play was regarded as the period of time between breakdowns in play (e.g., ruck/maul) in an attacking team's possession time, previously identified in the study of Reed and Hughes (2006).

3.3.2. Recording Procedures

The phases-of-play were captured by a digital video camera mounted on tripods and placed in a transversal plane (about 45 degrees in relation to the pitch lateral line) and elevated (about 12 meters high) level in relation to the performance field. No particular camera angle conditions were obeyed for these recordings since the selected digitization procedures did not require it. The selected recording angle covered at least the 22 m area (i.e., between the try line and the 22m line) as shown in Figure 3.1. The camera zooming rate was fixed in order to simplify the motion image processing (i.e., calibration procedures with TACTO 7.0 software; see Duarte, Araújo, Fernandes, et al., 2010, for software details). Video images were transferred to a computer via USB cable, using Windows Movie Maker software, and saved as wmv files.

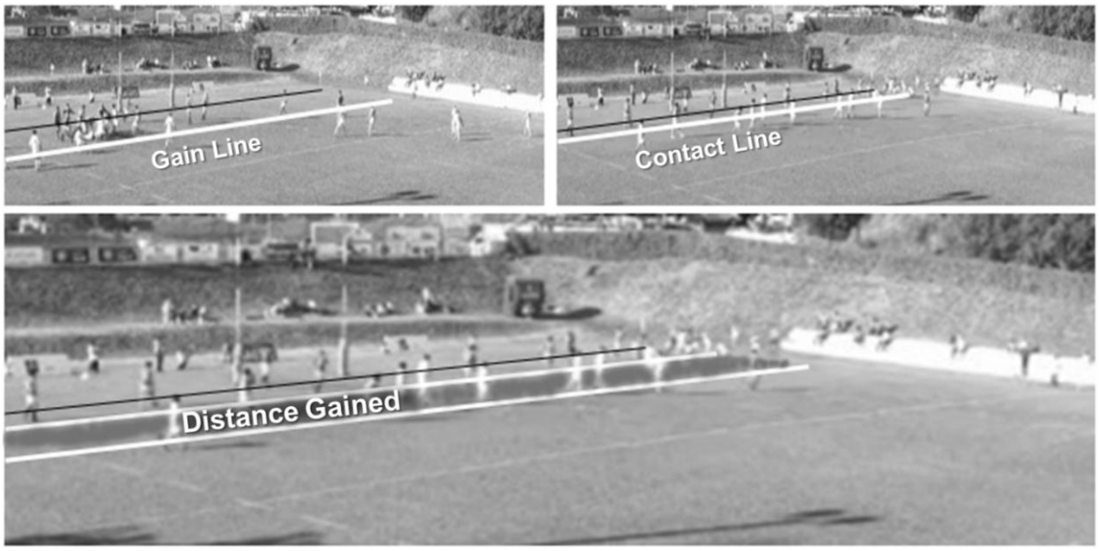

Figure 3.1. Original game scene taken by the camera. Demarcation of the variable distance gained and the respective lines considered for its computation (illustrative scene).

3.3.3. Data Inclusion/Exclusion Criteria

From the rugby union matches recorded performance footage was obtained for analysis. Inclusion and exclusion criteria for footage selection were established based on theoretical and methodological arguments. One of the essential criteria was to consider only filmed sequences of second-phase possession by an attacking team.

First-phase possession is characterised by an organized set-up. In this phase all players are conventionally positioned (generally attacking teams have depth and defending teams adopt a flat disposition facing the attack) at an established distance, which customarily leads to a zero forward momentum (Reed & Hughes, 2006). In contrast, due to the more uncertain initial conditions, second-phase attacks can lead to either positive or negative territorial gains for an attacking team. Rarely will all the players of both teams be in expected playing positions and the depth of the attack, in particular, might be weakly established. Since this study purports to examine self-organized collective pattern dynamics in rugby union match situations, the greater unpredictability of second-phase play situations is more conducive for achieving this aim.

Three other criteria for selection of the performance situations for analysis included: (i) occurrence when the attacking team was playing inside the opposition half, i.e., situations preceding scoring try possibility; (ii) initiation with a set piece, as a ruck or maul, and progressed to more open play; and (iii) termination with one of the following: (a) the attacking team moving forward (carrying or kicking the ball), (b) the defence regaining ball possession, (c) a game stoppage due to penalty or (d), the ball being put out of the field. We considered that the attacking principles of the game might be best assessed by determining the starting location of the contact line in a set piece and then studying it's evolution towards open play as result of agent interactions.

3.3.4. Grouping Successful and Unsuccessful Situations

Successful phases-of-play were considered to be those in which the attack progressed beyond the initial gain position (gain line) after a game stoppage (e.g., a ruck or maul), despite a first move backwards due to the distinctive rugby union rule that forbids the forward pass. Conversely, unsuccessful phases-of-play were regarded as all those that displayed the same backward movement first followed by a forward movement, with the final ball position (i.e., new game stoppage) being further from the try line than the original position where the attacking phase started.

3.3.5. Data Processing

Image treatment was achieved by a dedicated software package TACTO 7.0 (Fernandes, Folgado, Duarte, & Malta, 2010), with digitizing occurring at 25 frames per second. This software package allowed the extraction of x and y pixel coordinates of ball displacement along selected footages of phases-of-play. However, since this output does not correspond to real pitch area coordinates, the transformation of the digitized data to real coordinates (with reference to the pitch actual dimensions) was achieved through the Direct Linear Transformations method (DLT) using MATLAB 7.0 software. Using the same mathematical software, the time series positional data of ball displacement trajectories were obtained for each sample performance situation and analyzed to compute the variables of interest.

In order to capture the collective dynamics of rugby union second phases-of-play the first goal was to identify a potential coordination variable that could reflect the global dynamics of this performance sub-phase. The coordination variable selected for analysis was distance gained. Distance gained was calculated by the difference (in meters) between the ball's starting position in a developing attack (defining the "gain line") and its re-positioning over time (defining the "contact line"). The obtained value of this variable would be positive if the team with the ball progresses up the field in relation to its initial position, implying that the attacking team was successfully advancing to occupy opposition territory. On the other hand, the value would be negative when the ball retreated in relation to its initial gain position, implying a defensive advantage in territorial occupation dynamics. Time series of varying lengths were obtained from these computed distance data. Time series analysis methods were used to identify changes to the distance gained dependent variable in these performance situations based on analysis of ball displacement. This approach required the need to identify and describe pattern dynamics in the observed time series data.

A number of useful methods currently exist for qualitatively or quantitatively analyzing patterns in data from a single measured variable, or of the patterns of association between more than one variable over time (for reviews see Mullineaux, Bartlett, & Bennett, 2001; Mullineaux, 2008). However, as underlined by Mullineaux et al. (2001) sometimes the patterned relationship between data is not obvious, nor linear. Thus, an alternative method for depicting data variability and to assess the pattern forming dynamics of data across performance trials is to plot one variable as a function of another (Mullineaux et al., 2001).

In order to describe the collective system dynamics and identify patterns of interaction between variables the analysis started by a portrayal of distance gained as a function of normalized time. Position-time graphs allowed visual checking for signs of stability/and variability in that variable over time and for potential trends distinguishing between successful and unsuccessful team performance (further confirmed by means of a Linear Discriminant Analysis (LDA) performed in Matlab R2008). In addition the structural characteristics of the time series data were verified by means of state space reconstruction (Stergiou, Buzzi, Kurz, & Heidel, 2004). For this purpose a two-dimensional phase plot, with distance gained D (in meters) against its first derivate D' (in meters per second), was used to analyse agent interactions in successful and unsuccessful situations. Given that the sample performance situations studied had different durations, the respective time series trials needed to be normalized with respect to time for graphical comparison purposes.

Data were also subjected to quantitative analysis for measuring the variability within performance patterns. These selected methods included autocorrelation function (ACF) and approximate entropy (ApEn). The ACF assesses the dependency or stationarity of the distance gained time series (Borckardt, Nash, Murphy, Moore, Shaw, & O'Neil, 2008; Derrick & Thomas, 2004), being useful to appraise whether each distance gained data point is independent or unrelated to previous or succeeding observations (Borckardt et al., 2008). This technique was applied by plotting the Pearson product-moment correlation coefficient between data points at time t and time t + k-s lag for increasing values of k (Wagenmakers, Farrell, & Ratcliff, 2004). Accordingly, in order to understand how correlated the observations were with each other, and the scope of the long range dependency of the data, we computed autocorrelations for an array of 20 lags (.04-s lags ranging from .04 to .8) and plotted them in a correlogram to visually ascertain dependency. The ApEn method evaluates the complexity of time series data by quantifying the regularity or predictability within it (Pincus, 1991; Stergiou et al., 2004). According to Stergiou et al. (2004), in performance settings with a mixture of stochastic and deterministic systems, ApEn provides an effective statistical method. ApEn was considered appropriate for use since complex neurobiological systems are characterized by random, noisy deterministic and mixed data sets (Pincus, 1991). Due to inconsistent time series length, we used a normalized measure of ApEn, as suggested by Fonseca, Milho, Passos, Araújo, & Davids (submitted) with input parameter m = 2 and r = .2 (i.e., number of windows compared, tolerance factor, respectively) (Stergiou et al., 2004). For similar procedures see Passos, Araújo, & Davids, et al. (2009).

Subsequently, the qualitative data were also subjected to statistical analysis in order to verify relationships with quantitative analyses. A non-parametric Mann–Whitney U test was used to assess whether the two samples of performance situations (unsuccessful and successful phases of play) exhibited significant differences. Given that SPSS does not report an effect size index for the Mann-Whitney U test, we have computed the size of the effect (r) as $r = Z/\sqrt{N}$ (c.f. Rosenthal & DiMatteo, 2001).

3.4. Results

3.4.1. Distance Gained Behaviour

When plotting distance gained as a function of time, signs of stability in distance gained behaviours across time in successful situations can be observed (see exemplar data in Figure 3.2a). In a successful attacking performance, distance gained seemed to demonstrate similar patterns over time. As in the exemplar successful attack displayed in Figure 3.2a, in the entire sample (taking both successful and unsuccessful trials), this variable exhibited initially increasing, then decreasing negative values that approached zero. Since as successful attacks were considered those where the ball is carried beyond the gain line, in these attacks a zero cross-over is observed. However, when comparing successful attacking outcomes against unsuccessful attacks, as displayed in Figure 3.2b (exemplar trials), data curves although similar, achieved rather distinct values. This apparent trend in the performance data was observed over all trials and might be used to distinguish successful and unsuccessful patterns of attacking play.

An important observation is that the highest values for loss of territory (displayed by the maximum negative value of the series) seemed greater in unsuccessful attacking plays and occurred later in the time series data (see Figure 3.2b).

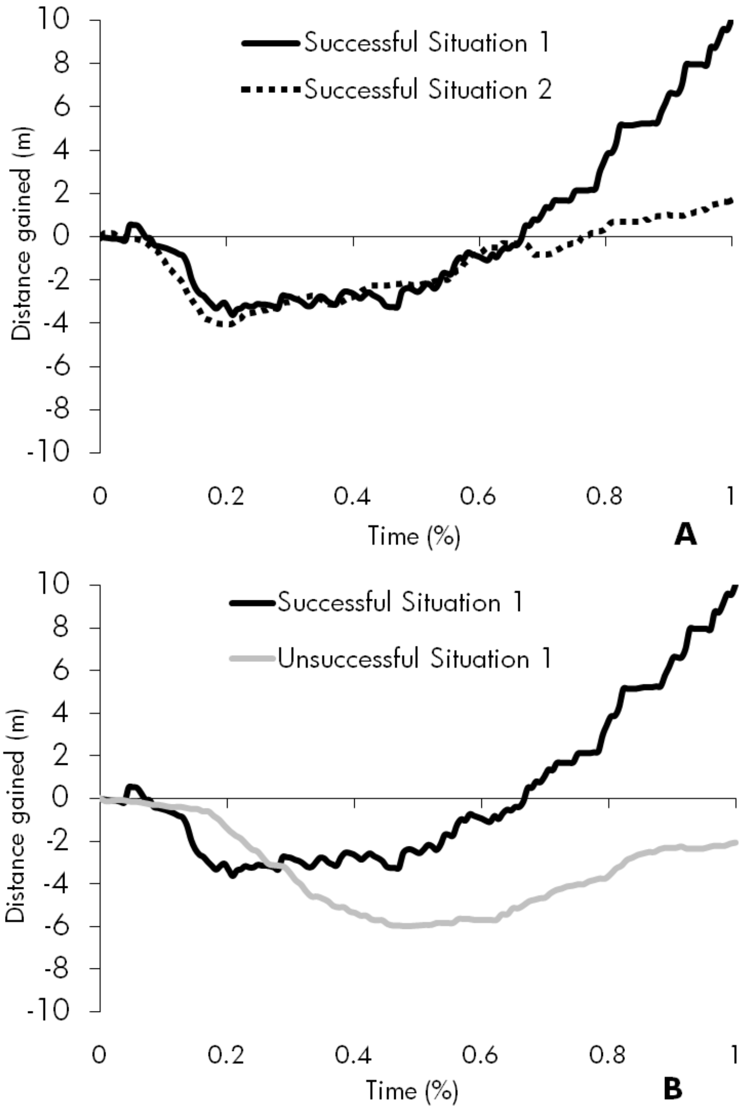

Figure 3.2. Distance gained as function of normalized time for randomly selected exemplar data: (A) two illustrative successful trials; and (B) one illustrative unsuccessful and one illustrative successful trial.

3.4.2. Maximum Distance of Retreat

Maximum distance of retreat in each trial and the corresponding normalized value were verified next. The maximum distance of retreat for each performance situation seemed to be related to the time of occurrence in the two groups (see Figure 3).

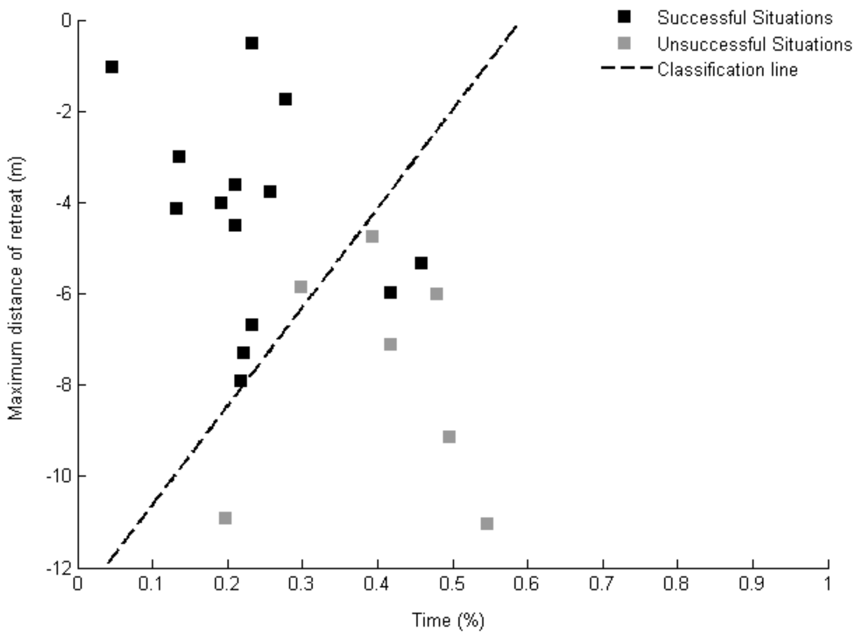

Figure 3.3. Maximum distance of retreat achieved as a function of normalized time for the entire sample trials (square marks) and classification line (dashed line) from linear discriminant analysis (LDA).

As illustrated in Figure 3.3, successful and unsuccessful attacking plays formed distinct patterns which were clearly discriminated by the classification line plotted (LDA). The data showed that in successful plays the maximum distance of retreat (further back from the initial gain position) achieved lower values and occurred earlier than in unsuccessful attacks. The latter displayed greater retreating values and occurred later in the time series.

Statistical comparison revealed that the mean percentage time at which the maximum retreat distance was achieved significantly differed between successful and unsuccessful attacks (Z = -2.61, p = .009, r = -.56), being higher in unsuccessful (N = 7; M = .40; SD = .12), compared to successful attacks (N = 15; M = .23; SD = .10).

Furthermore, the mean maximum retreat distance was shown to be significantly greater (Z = -2.72, p = .007, r = -.58) for unsuccessful attacks (N = 7; M = -7.83; SD = 2.54), than for successful attacks (N = 15; M = -4.16; SD = 2.19).

3.4.3. Territorial Gain Dynamics

A phase-of-play is regarded as successful when it ends with the ball in a more advanced position in the field than the initial point of the attack. As a result, if the team in possession retreats in relation to its initial starting position, distance gained and its first derivate will be negative. When the ball is moved closer to the try line, the distance gained may be still negative (if ball doesn't cross gain line) or positive (once the gain line crossover occurs) and its first derivative values will be positive. Regarding the representation of distance gained behaviour in system state space (see Figure 3.4), a phase plot of this variable as a function of its first derivate D' distinguished successful and unsuccessful attacks. Unsuccessful attacks showed more negative distance gained values, and more dispersed distance gained first derivate values. Successful attacks displayed more positive, but dispersed, distance gained values (i.e., the ball passed the initial starting position of the attack and was moved closer to the try line).

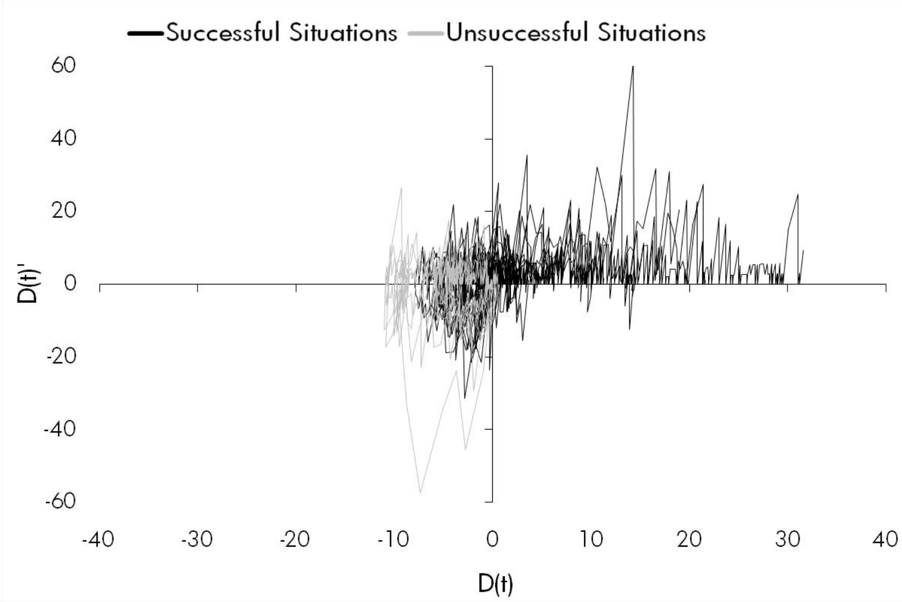

Figure 3.4. Two-dimensional phase plot of the distance gained D of the time series (on the horizontal axis) versus the first derivate *D'* (on the vertical axis) for the entire sample of successful and unsuccessful trials.

3.4.4. Variability of Distance Gained Time Series

In an attempt to understand the variability within the time series data, the autocorrelation method was applied to each distance gained time series. Results of this analysis suggested that observed behaviour over time tended to be highly correlated (Figure 3.5, 0.6<r<1), suggesting a long range dependence process unfolding in the data. The clear implication is that current behaviours were affected by prior behaviours in the same time series.

The correlogram produced from autocorrelation (Figure 3.5) may be regarded as evidence for the stationarity of the time series, since correlation values obtained for each time lag decayed very slowly even with large values of the latter. Figure 3.5 shows peak correlations at lags ranging from 1 to 20 data points, which indicate that even when the curve slides past a copy of itself, the fluctuations in the copy will line up with the original after being shifted, suggesting low levels of variability within these time series data.

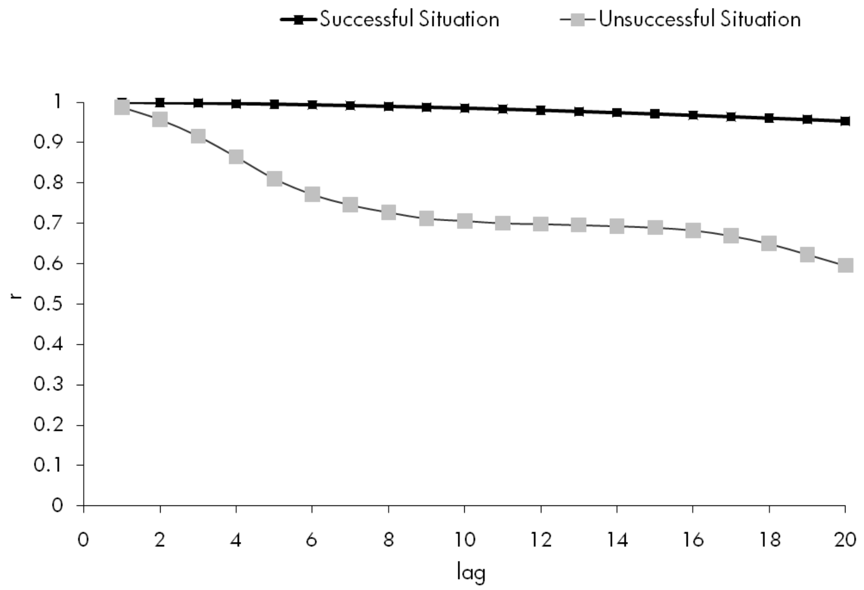

Figure 3.5. Autocorrelation of distance gained time series for success and unsuccessful illustrative trials (.04-s lags).

In order to compare the complexity of this subsystem, we considered the ApEnRatioRandom. For this normalised measure of entropy, values close to 1 indicate higher sub-system complexity and values close to 0 indicate more regularity. For successful attacks, ApEnRatioRandom ranged from .03 to .58 (N = 15; *M* = .29; *SD* = .18), whereas for unsuccessful attacks, these ranged from .3 to .63 (N = 7; *M* =.46; *SD* = .14). Such small values of ApEnRatioRandom suggest a regular predictable nature of the time series data from attacking trials, regardless of the outcome. However, predictability was more noticeable in successful attacking sub-phases which presented a smaller mean value of ApEnRatioRandom.

We performed a nonparametric hypothesis test to determine if there were statistically significant differences between the ApEnRatioRandom for successful and unsuccessful attacks. Results revealed that unsuccessful trials displayed significantly higher entropy values (Z = -2.01, p = .045, r = -.43).

3.5. Discussion

This study aimed to identify the collective dynamics of attack-defence rugby union sub-phases of play preceding the possibility of a try being scored. Particularly, the focus was on the dynamics of territory gained in the playing field by the team in ball possession. An important challenge in studying complex pattern forming dynamics in field invasion games is to identify relevant collective or coordination variables (see e.g., McGarry et al., 2002). In field invasion games, it is important to advance up field when in possession of the ball to score a goal or try. Consequently, some studies of pattern forming dynamics in team sports have highlighted the centre of the team as an important variable to analyse (e.g., Bourbousson, Sève, & McGarry, 2010b; Frencken & Lemmink, 2008). In past work, this variable has been regarded as representing the forward and backward progression of each team on the field of play. In our study however, given the particular task constraints of rugby union with respect to the offside law, distance gained was regarded as a suitable coordination variable for understanding structure in the second phases-of-play within this game. Coordination variables (known as order parameters or collective variables) and control parameters thought distinct are both relevant parameters and co-implicated in self-organized dynamical systems (Kelso, 1995). Nevertheless, as previously mentioned we didn’t aim at finding the control parameters implicated in the coordinated systems of rugby phases of play. Instead, the data presented in this paper showed the evolution over time (dynamics) of a variable that captured the collective actions, i.e., the synergies or functional groupings of players functioning as a social entity (cf. Kelso, 2009; Marsh, Richardson, Baron, & Schmidt, 2006; Bourbousson et al., 2010b). Our data demonstrated that distance gained was a variable capable of distinguishing between successful and unsuccessful attacks.

3.5.1. Distance Gained Behaviour

Two different performance outcomes were categorized in this analysis: crossing or not crossing the gain line defined by ball's initial position. Time series analysis of successful attacks showed signs of consistency in distance gained dynamics in the different trials analyzed. Similarities in dynamics of distance gained behaviour indicated that, in successful or unsuccessful attacks, a cycle or sequence of cycles existed with the ball being moved backwards and then forwards (see exemplar data displayed in Figure 3.2). This characteristic is in accordance with the description of rugby union as a team game of an intermittent character (Greenwood, 2003). However, instead of the 'stop and go' patterns of behaviour displayed by opposing players (Greenwood, 2003), our findings highlighted a more "backward and go" pattern.

3.5.2. Phase-of-play Dynamic Behaviour Distinguishing Success in Territorial Gain

Despite the similarities displayed in the dynamics of distance gained behaviour, this variable exhibited rather distinct values between successful and unsuccessful attacking plays. When the team in possession of the ball crossed the gain line, the pattern dynamics were characterised by different extents of backward and forward movements, compared to when the gain line was not crossed. The findings showed that successful attacks displayed lower values for maximum distance of ball retreat. Attacking teams tended to achieve those values sooner in the successful attacking phases, compared to unsuccessful phases when greater retreating values were recorded later in the time series (see Figure 3.3). In concurrence with these results, Greenwood (2003) regarded rugby union as a team sport characterised by patterns of order and disorder. He also proposed that the longer the phase-of-play, the greater the probability of disorder and the difficulty in gaining territory in the field of play. In similar vein, studies of space-time patterns in other team sports have demonstrated moments of stability and instability over time within the particular subsystems of games analysed (e.g., Bourbousson, Sève, & McGarry, 2010a; Bourbousson, Sève, & McGarry, 2010b; Frencken & Lemmink, 2008; McGarry, 2006).

Analysis of the dynamics of the maximum distance gained revealed that, although the backwards and forward movements are expected and common in any phase-of-play, the amplitude of those movements might be a distinguishing feature, indicative of a team's effectiveness in the attacking phase-of-play. This outcome was supported quantitatively by statistical analysis and was useful in categorizing successful and unsuccessful attacks. Successful and unsuccessful attacks were shown to be distinguished by the moment at which the peak distance of the ball's movement away from the gain line occurred (see Figure 3.3).

The relations between the proposed variable and other related variables, such as its first derivate, supported the distinction between successful and unsuccessful phases-of-play based on the dynamics of territorial gain. A greater backward movement of the ball (more negative distance gained values) and velocities closer to zero tended to characterise unsuccessful attacks. Successful attacks displayed more positive values indicating that the ball had been moved ahead of the initial position towards the try line, with rather dispersed velocity values. Together distance gained and its derivatives revealed thus information on attacking success in rugby union, in terms of territorial gain.

3.4.4. Variability of Distance Gained Depicting Success in Territorial Gain

Distance gained values revealed, for both successful and unsuccessful attacks, high levels of dependency within the time series data (through autocorrelation analysis), suggesting a low level of system variability (i.e., evidence of stationarity within these data series). This long range dependency process unfolding in the data coincided with the complexity analysis carried out through ApEnRatioRandom. Entropy analysis of distance gained for both successful and unsuccessful attacks revealed a regular or predictability nature. The approximate entropy values of distance gained matched autocorrelation values, given that the regularity assumed by the former was consistent within series dependency verified in the latter. As several authors have stated, the amount of order/disorder (chaos) within a system can be assessed by entropy measures (e.g., Sibella, Frosio, Schena, & Borghese, 2007). Sibella and colleagues (2007), for instance, have investigated patterns in climbing strategies and used entropy (geometric entropy) as one of their performance measures. According to these authors, the low entropy values were observed for some climbers suggesting lower levels of energy expenditure, greater fluency, and a more effective climbing strategy. Entropy was, in this way, a measure of effectiveness of the movement. In our study, although low, statistically significant ApEn differences were verified between unsuccessful and successful attacks, with higher ApEn values observed in the former, evidence of less regularity and more complexity. Similar to the study of Sibella and colleagues (2007), ApEn values for each successful and unsuccessful attacking phase-of-play may also be a useful measure of performance effectiveness in team games.

3.5.4. Collective Behaviour Conveyed by Distance Gained Dynamics

Regardless of the small sample of match situations studied and depth of our analysis, we may extrapolate some performance trends of distance gained dynamics that may allow prediction of the success or failure of phases-of-play in the team sport of rugby union. The present findings were consistent with Greenwood's (2003) proposal that, achieving a more advanced position in the field of play must be regarded as one of the key attacking principles in rugby union performance. He considered that this goal could be achieved either by the team in possession of the ball, or by the defending team by forcing the former to retreat. The emphasis in this study was the location and pace of ball displacement as a marker of successful territorial occupation. The achievement of a more advanced position in the field can be simply understood as successful performance and can be evaluated by the degree of territorial gain by assessing the position reached with the ball and its behaviour over time, i.e., its dynamics. Other studies have also shown that the analysis of the dynamics of a single variable could reflect the global dynamics of an entire neurobiological system (e.g., Vereijken et al., 1997) and of the dyadic interactions between team games players (e.g., Passos et al., 2008). Previous studies on the dynamics of decision making behaviours in sport have been mainly focused on team sports, typically in 1vs1 interactions (e.g., Araújo et al., 2004; Davids, Button, Araújo, Renshaw, & Hristovski, 2006), or in dyadic sports (e.g., squash by McGarry et al., 2002). This study advanced understanding by investigating interactions of multi-player sub-phases in field invasion team games. The findings supported previous research (e.g., Marsh et al., 2006; Bourbousson et al., 2010b) showing how two or more individuals may function as one entity. For instance Marsh et al. (2006) defined a "collective" as an emergent "social unit of action in which individual actors become part of a larger social entity, a collective, because it characterizes social interactions in their most abstract and basic form" (p.4). Our findings considered that players in a team interact with each other while cooperating in a goal-directed manner and that a team may be assumed a single entity or collective. Distance gained can be regarded as a coordination or collective variable capturing and describing the collective interactions between two teams in a match, revealing features that distinguish success of an attack during a phase of play.

Sustained on the ecological dynamics approach (Araújo et al., 2006) data from the present study supported the choice of distance gained as a variable which illustrates the dynamics of successful and unsuccessful second phases-of-play in rugby union. Analysis of ball displacement trajectory patterns (used to compute evolving distance gained) did reveal distinct behaviour in successful and unsuccessful attacks.

As mentioned before, the back and forward pattern displayed by this variable might be related with the task constraint of backward pass. That is, forward movement patterns observed in the game might be hampered by this rule. In this manner, this task constraint might work thus as meaningful information in the extent that influences the emergent game patterns. Conversely, the dynamics of the backwards or forward movement displayed by the ball may also influence how that constraint can be exploited. This circular or reciprocal relation between a rule of the game and the behaviour patterns might be worth of investigation in a further study.

Furthermore, the methodology used in this study proved useful in involving many social neurobiological system elements (such as each player's movement dynamics, referees, etc.). Although distance gained has been suggested as a coordination variable in this study, further work is needed to identify potential control parameters that might be influential in this context. To empirically and unambiguously verify the existence of a collective or coordination variable, qualitative changes must be identified caused by variation in the control parameter (cf. Kelso, 1995, 2009). In summary, this study showed that distance gained dynamics manifests a characteristic collective behaviour pattern that potentially captures the macroscopic order of a multi-player attack-defence sub-phase in the team sport of rugby union, depicting successful and unsuccessful patterns of play.

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Chapter 4

Prospective Information for Pass Decisional Behaviour in Rugby Union [3]

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4. Prospective Information for Pass Decisional Behaviour in Rugby Union

4.1. Abstract

Decision-making requires the perception of relevant information variables that emerge from the player–environment interaction. The purpose of the present article is to empirically assess whether players' decisional behaviour about which type of pass to make is influenced by the spatio-temporal variable tau. Time series positional data of rugby players were analysed from video footage taken in real match scenarios. The tau of the distance motion gap between attacker and defender was calculated, along with the duration of the next pass. Results revealed that the initial tau value predicted 64% of the variance found in pass duration. A qualitative distinction of tau dynamics between two periods of the approach between the attacker and the defender was also observed. We argue that the time-to-contact between the attacker and the defender may yield information about future pass possibilities. Additionally, the informational fields constraining attacker–defender interaction may be viewed as a convergent channelling of possibilities towards a single pass solution.

Keywords: Rugby union, Prospective control, Informational variables, Tau, Pass affordance.

4.2. Introduction

Since Gibson's (1966) conception about the reciprocal relationship between information and action in human activity, numerous researchers have integrated it into perception and action studies. In particular, the field of sports related research has a few empirical studies that use the ecological approach as a means of understanding sports performance (e.g., tau guidance in golf putting, Craig, Delay, Grealy, & Lee, 2000; optical information pick-up in basketball jump shooting, Oliveira, Oudejans, & Beek, 2006; information-based decisional dynamics; Araújo, Davids, & Hristovski, 2006). However, these studies are rare, and are hardly ever conducted with interacting athletes, and in actual competitions. The present study aims to give some input to the understanding of how information is guiding rugby players' action while performing in a real game scenario. Reading the findings of a range of sports research on perception and action from an ecological dynamics perspective (Araújo et al., 2006), decision-making can be regarded as emerging from constraints in the player–environment interaction that push the players to pick up informational variables about the possibilities for action afforded in the unfolding dynamics in order to accomplish performance goals. Decision-making comprises the particularities of transitions in the courses of action, based on the detection or selection of a new affordance. Moreover, perception of an affordance, taking into account its dynamic nature, underlies the prospective control of behavior (Fajen, Riley, & Turvey, 2009; Turvey, 1992).

Information is understood as being directly available and displaying the environment of performance properties and what they afford to the player(s) (Gibson, 1979/1986). Following an ecological dynamics perspective, which holds that the evolving interdependence between actions in the dynamical interactions between players and environment (Araújo et al., 2006), this study aims to investigate the informational influence of the closing gap between an attacker and an approaching defender on the attacker's decision to pass.

Dyadic synergies, in the form of attacker–defender interactions, can display non-linear properties (Araújo et al., 2006; Davids, Button, Araújo, Renshaw, & Hristovski, 2006) and be regarded as complex systems. Decisions and actions of the dyadic sub-systems of team sports are externally regulated by boundaries of the information fields geared by constraints, such as interpersonal distances among players, border line markings, dimensions, and rules of the Rugby game (Passos et al., 2008). Random interactions between system components (e.g., players in a dyad) can change into more organized forms of interactions, as a single key system parameter changes in value (e.g., changes in players' relative velocity). But these changes only condition the attacker–defender dyadic system behavior when entering in regions of self-organized criticality (e.g., within 4 m of interpersonal distance as suggested by Passos et al., 2008).

4.2.1. Prospective information unfolding players–environment interaction and decisional behavior

Prospective control is a straightforward ecological aspect of human behavior. In essence it is the perception of the flowing relationship between the individual and the environment that allows goal-directed action to be updated constantly and ahead of time. Variability and instability are game features, and pre-established game plans and strategic decisions appear unlikely to be the main influence on a player's decisional behavior in the actual game. In fact, players must be able to perceive the game, and to prospectively perceive its ongoing dynamics in order to achieve their (and the team's) goals. Instead of simply reacting to what happens, to rely solely on memory and cognitive inference processes, which would disregard the evidence of the changing interactive nature of the surrounding environment, action must mostly be dynamically controlled ahead of time by picking up relevant prospective information. Consistent with this view are studies by (Craig, Berton, Rao, Fernandez, & Bootsma, 2006; Craig et al., 2009) that showed how the continuous non-linear change in the direction of a ball's flight, caused by the Magnus force, influenced expert goalkeepers' ability to accurately perceive the ball's future arrival point. These authors considered that movement during interceptive actions is better characterized by a reliance on prospective information carried in the perceptual flow than on computation-based extrapolations of the current situation (Craig et al., 2006).

As Turvey (1992) put it, when ''positioning oneself to receive a pass in a game of football, it is essential to see what movements are possible, what encounters are possible, and to control behavior accordingly'' (Turvey, 1992, p. 174). Likewise, to adequately guide the approach towards a defender while receiving the ball from a teammate and then passing it away for another attacking support player, prospective information is needed. Successful performance requires that the player is attuned to relevant information unfolding during such game interaction and detects and uses this information to guide action to achieve performance goals (Araújo, Davids, & Serpa, 2005). In keeping with this, that is to say that in a rugby game the player must act to pick-up information in the game, and the information he/she picks up allows him/her to act, the aforementioned interaction enters this continuous perception–action loop.

For the prospective control of action, Lee (1998) considered that all goal-directed movement (e.g., upcoming collisions: Bootsma & Craig, 2003; attacking forehand drives in table tennis: Bootsma & van Wieringen, 1990) requires the prospective guidance of the closure of motion gaps. A motion gap is any gap between a measurable current state and a goal state (Lee, Craig, & Grealy, 1999; Trevarthen, 2007). In this manner, prospective control of these gaps means that there is information about the way the gap is closing that can be extrapolated into the future and can be used to adjust and control online goal-directed action (Lee et al., 1999). Tau of a motion gap (t(x)) specifies the time that gap would take to close if the rate of closing were kept constant (Lee, 1998; Trevarthen, 2007; von Hofsten, 2007). Therefore, it specifies both spatial and temporal information. Furthermore, though materialized as a ratio function between the current size of the motion gap (x) and its current rate of closure ($\dot{x}$), Lee (1998) emphasized that it is directly perceivable without the prior need to enter and compute x and $\dot{x}$ (see also, Kim, Turvey, & Carello, 1993). Hence, according to Lee et al. (1999) the control of these motion gaps is founded on the principle that the relevant information encapsulated in the tau of that motion gap can be picked up through changes in the sensory array and allows for the actor to adjust the way the gap is closing to achieve the desired goal. One important aspect is that it is regarded as what the individual perceives for ‘‘timing actions relative to the environment’’ (Trevarthen, 2007, p. 7). A correspondence between this timing of specific actions with specific tau-margin values has been empirically evidenced in sports research (e.g., hitting an accelerating ball by Lee, Young, Reddish, Lough, & Clayton, 1983). For instance, Bootsma and Craig (2003) showed in a collision judgment task that these judgments were prospectively guided by tau information. These authors assumed that their findings pointed towards the participants’ sensitivity to the evolution of tau over time (Δtau). With respect to the team sport of rugby, tau has been recently considered as a candidate informational variable that can be used to control a player's action during typical game situations (e.g., gap ''passability'', Watson & Craig, 2008; detecting deceptive movement, Brault, Bideau, Craig, & Kulpa, 2010).

Likewise, the study of Passos and colleagues (2008) may be regarded as supporting the view of tau influencing players' actions. This is because the parameters (interpersonal distance and relative velocity) driving the identified organizational states of attacker–defender dyads (i.e., try or tackle) are inextricably tied up in the tau variable.

Along these lines, the approximation between attacking and defending players and the subsequent pass is not expected to be controlled by means of processing spatial information variables, and computing and monitoring the velocities to achieve a distance value in order to fit a programmed pass to a teammate. Instead, this approximation and the ensuing behavior are regarded as being directly guided by the spatial/temporal information specified by tau (Lee, 1980). Even though some researchers have been probing the information guiding action in sport, hardly any have attempted to identify information that players may be attending to during decision-making performance in an actual game. Focusing on specific game situations of the actual match, such as second phases-of-play in which the two sequential passes are made successfully, the hypothesis on the basis of this study was that a relationship might exist between the information specifying time-to-contact with an approaching defender (i.e., tau of this closing distance motion gap) and the prospective control of the type of pass executed.

Accordingly, the present study intended to identify the way a particular informational variable such as tau might be used to guide action in the game of rugby. However, the purpose was not to identify the informational variable being used by players, but rather to identify one of the potentially relevant variables available in the interaction between the players and the environment in an actual game. This question has also practical value, since it takes into account the construction of representative task designs (i.e., tasks that represent the conditions towards which the experimental or practice results are intended to apply; Araújo, Davids, & Passos, 2007; Brunswik,

1956) both in research (in the design of experimental tasks), and in practice (to define practice task constraints) to study/develop perception–action coupling.

4.3. Methods

4.3.1. Data/sample

To constitute the sample for this preliminary study, 13 video scenes of rugby second phases-of-play near the try line were selected from actual rugby union matches.

The criterion used for match selection was to include only those matches played by the ‘‘best’’ teams (according to previous classifications in this championship), and where there was an ‘‘expected equilibrium’’ between the performance of both teams involved in each match. Therefore, the matches analyzed were the semi-finals and the final male senior matches of both the Portuguese Premier League Championship, and the Portuguese Cup (2007–2008 season). For scene selection three criteria were used. The first was to consider those scenes where the attacking team was playing in the opponent’s half pitch within the 22 m area, i.e., between the try line and the 22 m line (situations that precede the possibility of a try being scored). Second, only second phases-of-play were considered given the less ruled constrained onside position. By second phase-of-play we mean all open play following a ruck or a maul. Conversely, first phase-of-play or set plays, comprise all the restarts of play following a scrum, line-out, drop-out or free kick (for a detailed description of this game stoppages see the International Rugby Board, 2010). While in the first phases players are initially positioned beyond an offside line greatly distanced from the game stoppage line (i.e., 10 m behind the touchline in the line-out and 5 m behind the backfoot of the last player in a scrum, cf. International Rugby Board, 2010), in second phases-of-play the onside position is much less constrained (i.e., the offside line runs from the backfoot of the last player in either the ruck or the maul, cf. International Rugby Board, 2010). This difference counts for higher variance in the initial distance of the approach run between attackers and defenders in subsequent open play thus is in line with this study’s purpose. Third, given the aim of investigating the information underlying a successful attacking behavior, only phases that ended with an effective pass to a teammate were considered, that is to say, passes in which the attackers passed the ball and the receiver caught the ball. Additionally, it is worth noting that the selected scenes were taken without making distinction on characteristics of the approach between players (e.g., initial distance, players' velocity of approach), nor on the subsequent pass type (e.g., long, short), nor on whether it was made by different players. The 13 scenes considered were all that accomplished the just mentioned criteria, in the high-level matches mentioned before.

The matches were recorded using two digital video cameras (Canon HDV-20 and Panasonic NVGS21) each facing each half of the rugby pitch. The selected footages (sampled at 25 Hz) were digitized using TACTO software (for software details see Duarte, Ferreira, Folgado, & Fernandes, in press; Fernandes, Folgado, Duarte, & Malta, in press) that allowed us to obtain the players' relative positions as pixel coordinates over time. The time series of pixel coordinates were afterwards transformed into real coordinates by means of Direct Linear Transformations method (2D-DLT) using Matlab 7.0 software. The data were analyzed in a xy-coordinate system with the x-axis corresponding to the rugby pitch's touch line and the y-axis the try line. From these time series positional data (real coordinates) the target parameters of analysis were computed.

4.3.2. Variables

For the purposes of the present study the movement analysis included the time series positional data of: (a) the first attacking player who received the ball (first receiver) from the onset of the second phase-of-play (i.e., play immediately following a ruck or a maul) and made an intentional and accurate pass, (b) the defending player (defender) marking the first receiver, and (c) the attacking player (second receiver) who received the ball from the first receiver. The time period considered as the key period of approach where the gap was closing between the attacker (i.e., the first receiver) and the defender began when the first receiver got the ball and lasted until he passed the ball to the second receiver.

According to Lee (1980) as tau informs us about how a motion gap is closing it can also be regarded as affording information about a future course of action. The motion gap under analysis in this case was the distance motion gap between the first receiver and the defender (in the x-axis only). This distance motion gap was calculated using the time series positional data of these players, in each frame of the period of approach. The tau of this closing distance gap was obtained for each frame of the same data period by applying Lee's (1980) formulae of tau ($\tau(x) = x / \dot{x}$), which concerns the ratio of the current size of the motion gap, x (i.e., the distance between first receiver and direct defender) and its current rate of closure, $\dot{x}$ (i.e., the instantaneous velocity of this approach between players). Negative tau values mean that the motion gap is closing, with tau being the first-order time-to-closure.

4.3.2.1. Approach variables (candidate informational variables)

For this study, the tau values of the closing gap between the attacker and defender that were considered are: (i) the initial value of tau, when the first receiver gets the ball at the onset of the second phase-of-play, (ii) the final value of tau, just before the ball has left this attacking player's hands, and (iii) mean tau, calculated as the mean of tau values during the approach between these players.

The following analysis mainly focuses on the relation of tau variables with pass related variables, but also of other variables potentially influencing the decision outlined in this triad subsystem ''first receiver'' – ''defender'' – ''second receiver''. Therefore, alongside tau variables other kinematic discrete variables of the attacker–defender approach were also analyzed, such as the (i) initial distance between the first receiver and the defender, obtained by the difference in the x-coordinate of the first receiver at the first frame of ball possession and the x-coordinate of the defender at the corresponding frame of the positional data time series, and (ii) motion gap duration, measured as the length of time elapsing during the approach of the defender towards the first receiver and while the first receiver is in possession of the ball.

4.3.2.2. Pass variables (action variables)

The pass variables considered (regarded as means differentiating the type of pass) were discrete measures of: (i) pass distance (see Figure 4.1) that was obtained by subtracting the difference in the y-coordinates of the first receiver at the last frame of ball possession and the y-coordinates of the second receiver player at the first frame of ball possession; (ii) the pass duration that was operationalized as the length of time taken for the pass (or ball flight time), and it was measured from when the ball leaves the hands of the first receiver until the instant it arrives in the second receiver's hands;

(iii) the pass angle (Figure 4.1), which was measured at the moment of the pass (when the ball leaves the first receiver's hands), and was defined between a line that crossed the x-coordinates of the first receiver and the position where the ball arrives with the pass at the second receiver; and (iv) the pass velocity was obtained by calculating the first time derivative of ball flight (i.e., pass velocity = pass distance/pass duration). The classification of pass (as short or long passes) by means of these variables can also be found in the rugby literature (Biscombe & Drewett, 1998).

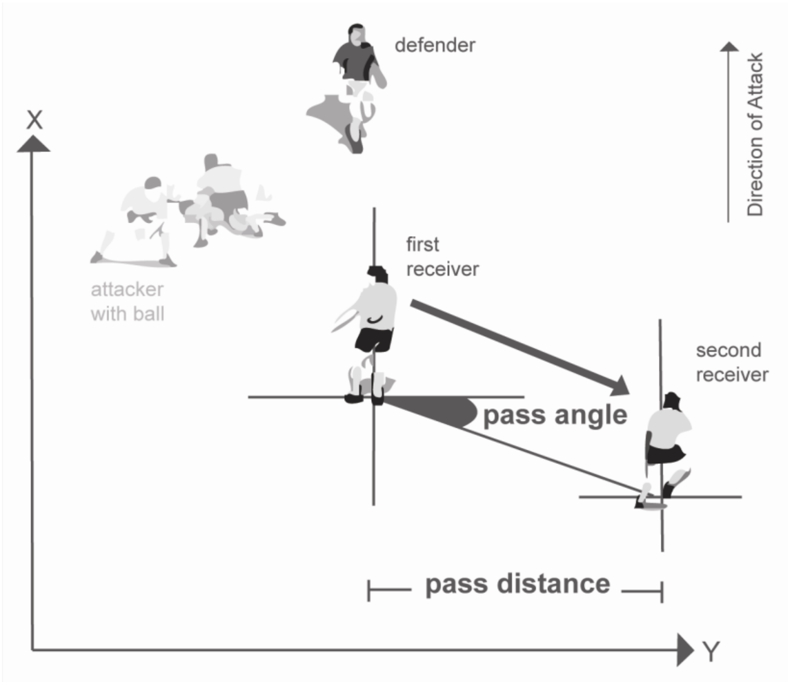

Figure 4.1. A schematic representation of pass distance and angle in a second phase-of-play.

4.3.3. Data analysis

The variables emerging in the approach between the first receiver and the nearest defender (i.e., initial, final and mean tau, motion gap duration, and initial distance attacker–defender), were regarded as potential spatial–temporal candidate variables informing players about what action to take next, more specifically informing decisions about the type of pass to make given the ensuing situation.

The degree of the relationship between the informational variables and the pass variables was tested with the parametric Pearson Product Moment correlation. In order to assess the nature of the relationship between pass variables (cf. Bhattacharyya & Johnson, 1977) considered as dependent variables and approach variables (informational variables), that are potentially independent or predictor variables, a linear regression analysis was also performed.

Another aspect that we considered for analysis was the variability in tau between the situations under scrutiny in this study (inter-trial variability) during the attacker–defender approach. Variability was considered not only after the former received the ball (the motion gap considered), but also in the approach before this first pass was received. This tau variability over time was calculated by means of the continuous method of multiple-situation variability, the point-by-point variability band (James, 2004). This method involves the computation of the mean and standard deviation for each corresponding data point (each frame = 0.04 s) of the tau series across the situations under analysis. For the purpose of this analysis, we considered the last 18 data points (one data point per frame) of the approach ''Without the ball'' (i.e., just before the 1st receiver gets the ball), and the 12 data points of the approach ''With the ball'' (i.e., just after the first receiver gets the ball). The criteria used to set these points' boundary for each period was to comply with the mean percentage of points corresponding to each period for all the trials ($N_{\text{approach ''Without the ball''}}$ = 13, $M_{\text{\% data points}}$ = 60, SD = 10%; $N_{\text{approach ''With the ball''}}$ = 13, $M_{\text{\% data points}}$ = 40, SD = 10%). The tau point-by-point variability band is thus formed by the outcome single value for each group of data points representing an instant in time (James, 2004). In addition, in order to quantitatively assess the differences between the two periods of approach in the point-by-point mean tau analysis, the Wilcoxon signed rank test was performed.

Intra-trial tau dynamics were assessed individually by graphical inspection using the same criteria used in the point-by-point variability method to set the points' boundary considered in each period. Moreover, we assessed whether the two periods of approach (''Without the ball'' and ''With the ball'') showed differences in the evolution of tau by performing a Wilcoxon signed rank test on the slope of the trend line corresponding to each period data point, which was considered to reflect how tau changes over time.

4.4. Results

4.4.1. Distance motion gap

For the entire sample, we calculated the longitudinal distance motion gap (i.e., considering the field lateral line as the x-axis of reference) between the attacker and the defender. As expected, it was shown that it decreases over time (see Figure 4.2), indicating that the players are getting closer to each other through the closing of this distance motion gap.

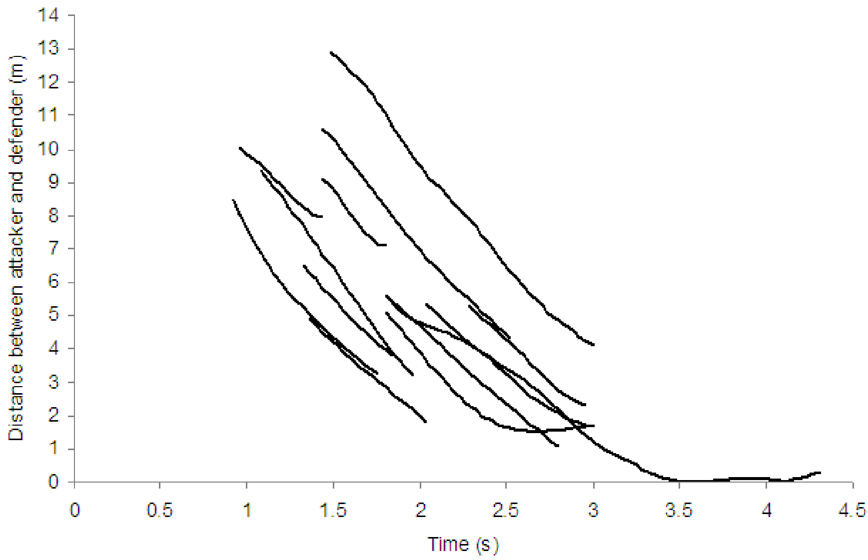

Figure 4.2. Distance between the first receiver (with ball) and the marking defender over time for all the analyzed trials (N = 13).

4.4.2. Informational variables and pass variables

Pearson's correlation tests showed significant negative correlations between pass distance and the initial tau value of the motion gap and also between pass duration and the initial tau value of the motion gap (r_p = -.795, p = .001, and r_p = -.802, p = .001, respectively). Likewise, a significant negative correlation was also found for pass distance and the mean tau of the distance motion gap representing the approach between the first receiver and the defender (r_p = -.58, p = .036). No significant correlation was however found between all the other pass variables and informational variables, such as the final tau value, initial approach distance, and motion gap duration (p > .05).

Given that pass distance and pass duration are highly correlated (r_p = .85, p < .000), defining both the type of pass made, we opted to perform a regression analysis with only the pass duration. The results leaned towards a linear relation between pass duration (dependent variable) and initial tau (independent variable) (R^2 = .64; F = 19.79, p < .001; β = -.43, α = -.18, p < .001) as shown in Figure 4.3.

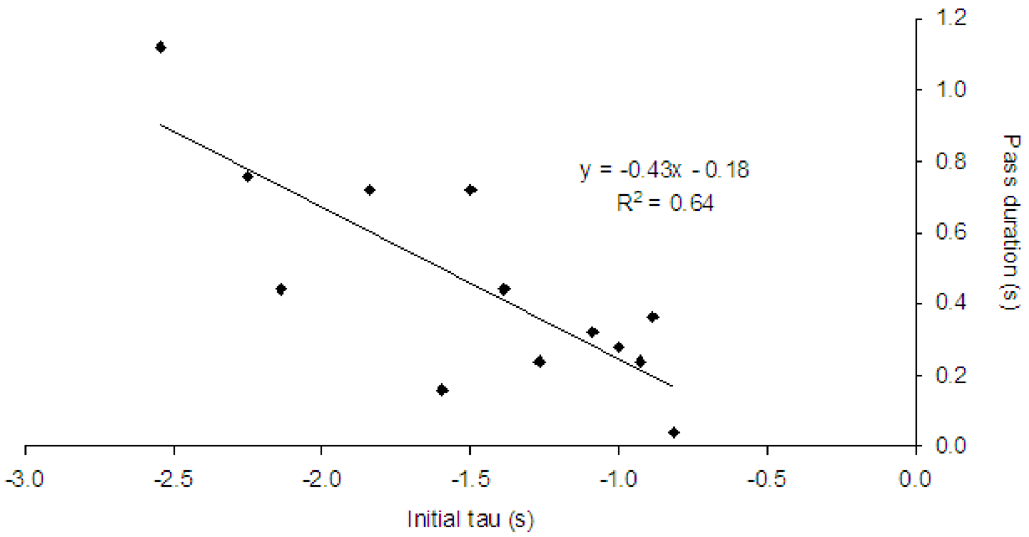

Figure 4.3. Dispersion diagram of pass duration (dependent variable) as a function of the initial tau value (independent or predictive variable).

4.4.3. Inter and intra-trial tau variability

The degree of variability or dispersion in the entire time series tau data (inter-trial variability) in the period up until the first receiver gets the ball (i.e., approach ''Without the ball'' – left hand side of Figure 4.4), and after receiving the ball from the onset of the second phase-of-play (i.e., approach ''With the ball'' – right hand side of Figure 4.4) was accessed by means of the point-by-point variability method. A Wilcoxon signed ranks test revealed that the point-by-point mean tau values computed were significantly greater (Z = -2.67, p < .005) for the first period of approach ($M_{\text{Without the ball}}$ = -3.56; SD = 3.02) than for the latter ($M_{\text{With the ball}}$ = -1.24; SD = .12). Moreover, these periods displayed dissimilar point-by-point mean and standard deviation band's behavior. Note the higher inter-trial variability during approach ''Without the ball'', while a low variability in the approach ''With the ball''. A higher standard deviation was found for the approach ''Without the ball'' data set while a lower standard deviation during the approach ''With the ball''. This indicates that these tau data points tend to be much closer to the mean tau in the approach ''With the ball''. In the approach ''Without the ball'', the higher standard deviation indicates that the tau values during this period are spread out over a larger range of values.

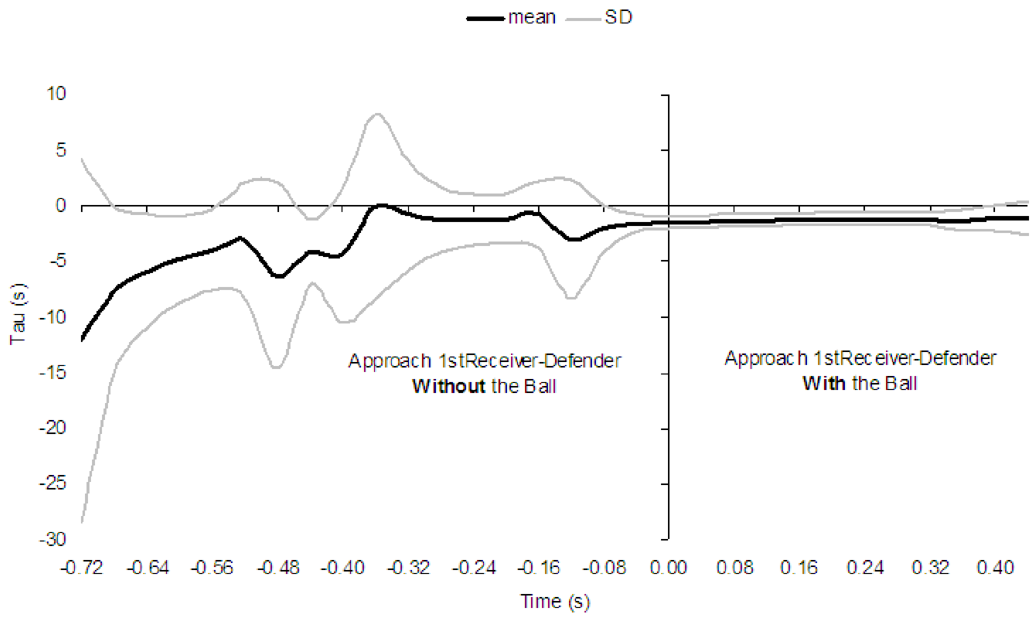

Figure 4.4. Point-by-point tau average band (M ± SD) of the distance motion gap between the 1st receiver and the defender (James, 2004) for all the analyzed trials (N = 13). X = 0 marks the instance the 1st receiver receives the ball from the onset of the second phase-of-play, i.e., the beginning of the part of the approach ''With the ball''.

Besides the exhibited inter-trial variability when analyzed individually, in each of the sample situations tau displays a dissimilar behavior before and after the first receiver gets the ball from the onset of the second phase-of-play. Each trial exhibits decreasing values with a more pronounced curve behavior in the first period, but a similar curve shape, and with a smooth continuity over time (see the illustrative trials portrayed in Figure 4.5). When compared statistically, the slope was significantly different between the two periods (Z = -3.04, p = .001). The slope describing tau as a function of time is likely to be significantly higher during the approach ''Without the ball'' (N = 13; M = 12.12; SD = 11.61), than during the approach ''With the ball'' (N = 13; M = 1.88; SD = 2.24).

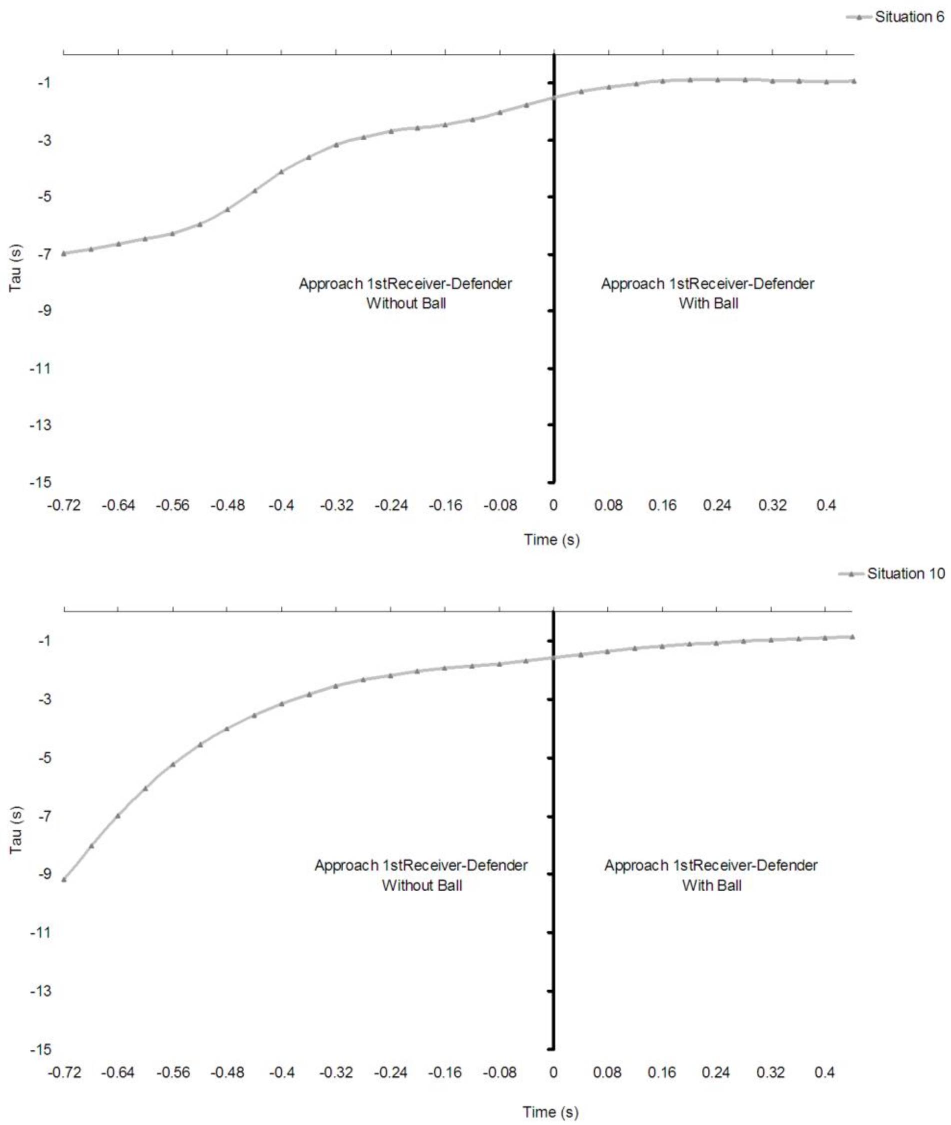

Figure 4.5. Tau dynamics over the last 18 data points of the period of approach ‘‘Without ball’’ and the first 12 data points of the period of approach ‘‘With ball’’. X = 0 marks the instance the first receiver receives the ball from the onset of the second phase-of-play, i.e., the beginning of the part of the approach ‘‘With ball’’. Examples are taken from situation 6 and situation 10.

4.5. Discussion

This study aimed to obtain further empirical support for the understanding of how information guides movement. More specifically we set out to explore in an actual game of rugby, how information, which is directly picked up from the way the motion gap between the defender and the attacker closes, influences the type of pass that is made by the attacker during second phases-of-play.

4.5.1. Information that influences pass behavior

Potential informational variables, defined in the dynamics of the approach phase between the first receiver and the nearest defender, were analyzed to see whether they influenced the type of pass made by the first receiver. The distance between the attacker and defender was shown to decrease over time indicating a closing motion gap. Although involving different players in different matches and game situations, some pass characteristics, namely pass distance and pass duration, were found to be significantly correlated and linearly related with the initial tau value of the closing distance motion gap. The initial value of the invariant tau specifies how the gap between attacker with the ball (first receiver) and the defender is closing over time at the instant the first receiver gets the ball. This is in line with the key idea of prospective control underlying general tau theory (e.g., Lee & Young, 1985; Montagne, 2005; von Hofsten, 1993). As Grealy, Smith, and Pepping (2007) commented about timing of initiation of the action ‘‘it is frequently not critical when a movement starts-just so long as it does not start too late’’ (p. 122). Likewise, the critical information (for pass possibility perception) might not be perceived at the instant of a given action but prior to that (in this case, in the initial tau of the distance between opposing players). This suggests prospective guidance of movement. The initial tau may be regarded as prospective in the sense that the rate of change of the distance between the players informs the first receiver about the adequacy of their current approach movement in order to perform a pass to a perceived teammate positioned closer or further away from him (corresponding to a short or longer pass). One may assume that with this online guidance, players prospectively perceive which pass is a possible action. Above all, our results may be viewed as demonstrating that it is at the instant the player receives the ball (initial tau) that he perceives whether the time remaining to collide with the defender will allow him to perform that pass. Along these lines, initial tau was therefore found to prospectively guide the behavioral decision about the type of pass. A regression analysis reinforced these findings. The observed strong relationship (accounting for a high percentage of the variance) between an informational variable (initial tau) and a resulting action (pass) supported the hypothesis that perceptual variables embedded in the dynamics of the changing gap between attacker–defender influenced decisional events, such as when and how to pass. More specifically, the regression suggests that the closer the tau value is to zero, that is to say the less time there is until the gap between the players is closed, then the shorter the duration of the pass. In terms of action organization, longer passes will obviously take longer and will only occur when the initial tau value specifies a longer time frame in which the action can take place. Furthermore, if the decision to pass further or shorter was only made at the moment it is observed, one could expect that the time remaining to contact the defender when the attacker (first receiver) passes the ball (i.e., final tau) would be also correlated with the variables associated with the length of pass (duration and distance). However our data did not find this relationship to be significant. This means that when the attacker receives the ball, perceiving the way that gap to the defender is changing may allow him to perceive a future state of that gap and essentially the future action possibility.

Only tau and not any other approach variable, such as the initial distance between the players (attacker–defender) or motion gap duration, was predictive of any pass characteristics. This provides support that instead of making complicated computations and inferences about kinematic measures of the approach per se, players are simply picking up relevant information from the dynamics of the gap closure as specified by tau. That is, it emphasizes the perception of relevant information embedded in the dynamics of the sporting context. In other words, as stated by Bastin, Craig, and Montagne (2006) a prospective strategy does not entail the identification in advance of the place or the time of contact. Instead, action-relevant information (i.e., the possibility of a pass longer or shorter before an upcoming collision) is specified in the variable tau that is directly available to be perceived in the interaction between the attacker and the defender. These findings can be seen as being in accordance with the theory of direct perception (Gibson, 1979/1986), which supports the idea that perception occurs in the absence of complex computations of kinematic changes. Given that the parameters that determine the type of pass that the player made were shown to be related to the initial tau values, the perception of the pass affordance is suggested to be related to the perception of this higher order variable. This is in accordance with Delafield-Butt and Schögler's (2007) interpretation of tau and its derivate variables as being relational invariants of a functional organism–environment interaction, and Turvey's (1992) assertion that affordances more than specific action possibilities are interaction or relation possibilities. Accordingly, our findings suggest that decisional behavior or tactic action is not primarily dependent on processing mechanisms of the visual information picked in the approach. Instead, tau information is invariant information perceived directly in the flow field of players' environment. This excludes the need for processing other dimensions of distance, such as velocity or acceleration of the approaching player, with tau alone being sufficient to guide action. Our hypothesis suggests that the direct perception of the time remaining until contact with the defender might be said to afford the choice of pass (long or short, slow or fast) for the attacking rugby player.

As stated before, one important implication of the general tau theory is prospective control (Pick & Pick, 2007). Although the small number of scenes selected for analysis in the current study means we have to interpret the findings with a certain degree of caution, we have however shown from our data how the initial tau may be influencing subsequent action and may therefore support the notion that this variable specifying time-to-contact of the closing gap between attacker and defender is being used as a perceptual variable to prospectively guide pass decisional behavior. Furthermore these findings are consistent with those of other studies on prospective control of action (Kayed & van der Meer, 2009; Lee, Georgopoulos, Clark, Craig, & Port, 2001; Montagne, 2005). Additionally, our results also agree with studies that show how decisions are influenced by prospective information carried in the perceptual flow (e.g., Craig et al., 2006, 2009) and also how prospective control allows for the control of future events and opportunities for action to achieve intended goals (e.g., Turvey, 1992). The findings are also in agreement with the long-standing empirical evidence of timing of specific actions with specific tau-margin values (e.g., Lee & Reddish, 1981; Lee et al., 1983; Wagner, 1982).

4.5.2. Tau inter-trial variability

The predictive relationship revealed between initial tau and pass distance prompted the exploration of tau variability during the approach phase of the attacking runner. Analysis on inter-trial variability showed that tau evolves in a particular way for each situation, being mainly different between situations in the period of approach without the ball. The inter-trial variability was somehow expected since it includes attacker–defender dyads with different starting conditions. For instance, even for two similar situations in which the players approach each other with the same relative velocity (gap closing at the same rate), if the approach of each situation starts from different interpersonal distances (different gap distances to be closed) the value of tau would be different.

4.5.3. Attacker–defender dyad constraints and the detection of pass affordance

When regarding each situation individually, a qualitative distinction of tau dynamics between periods of approach was observed. This was quantitatively corroborated by the significant differences of the slope of the tau dynamics trend line between each period, for all the analyzed situations. In the overall situations and for both periods of approach, tau value dynamics revealed a closing distance motion gap between attacker–defender, differing however in the way tau changes over time, i.e., the rate at which the gap is closing is significantly higher for the ‘‘Without the ball’’ approach. This difference between periods can be explained by the local constraints that come into being at the moment players are engaged in a duel situation, i.e., the attacker with the ball affords tackling for the defending player. In particular, the local constraints change from a strictly informational coupling between players to a more critically close to a physical contact circumstance. This view may be assumed in light of Passos et al.’s (2008) work which showed that decisional behavior of the dyadic sub-systems of team games is regulated by information fields formed by the embedded contextual constraints (Juarrero, 1999). Moreover, previous studies (Passos, Araújo, Davids, Gouveia, & Serpa, 2006; Passos et al., 2008) on rugby attacker–defender dyads, empirically demonstrated that the dynamics describing these dyads changes, or transits to other organizational states, as the interpersonal distance decreases (Passos et al., 2006). Furthermore, it was demonstrated that within a critical interpersonal distance changes in relative velocity embody changes in the informational field governing this system, converging to a single action solution (Passos et al., 2008).

Consequently, as also suggested in these studies, when entering into the period of approach ‘‘With the ball’’, players might be entering into a region of self-organized criticality conditioning the dyadic system behavior. During the approach ‘‘Without the ball’’ until the ball is received by the first receiver, the space between this player and the defender closes much faster (as shown by the slope of the trend line during this period). But once the first receiver has the ball (approach ''With the ball''), the players enter into a second order relation (duel) where the influence on each other is higher, requiring a greater need to accommodate these new constraints, thus increasing the need for better perceptual attunement to relevant informational variables that will inform decisional behavior. In this way, it may be assumed that players are perceptually exploring the information that evolves over time to detect and use, within the emerging and decaying affordances, the best pass affordance.

The design of the present study had the advantage of allowing for the examination of informational parameters embedded in the unfolding interaction between the players and environment and its relation to the action parameters that determine successful performance (effective passes) in the actual game. This methodology and approach might provide a possible way of assessing increased levels of attunement to relevant information variables such as tau during the unfolding interaction. Its exploration and use may provide an important means of guiding goal-directed action to increase the level of successful performance, as argued by Araújo and colleagues (Araújo & Davids, 2009; Araújo et al., 2005; see also, Huet, Camachon, Fernandez, Jacobs, & Montagne, 2009). However, it is worth noting that we did not aim at investigating the development of this coupling between information and action. This was the reason for having players from the same expertise level (illustrating the highest national level). Nonetheless, according to a review by Montagne (2005), the fact that mainstream literature sustains a qualitatively similar regulation of behavior between levels of expertise, suggests that an information–action coupling is easily attained with practice and is present among different levels of player ability. Therefore, we may assume that the coupling between information (tau) and action (pass) would be also verified with novice players after some practice. However, Montagne highlighted that perceptual attunement, in contrast, requires a large amount of practice and is expressed by the experts by their lower overall variability when compared to novices. Besides, attunement entails the enhancement of the relation between information and movement in a functional way (i.e., continuous goal-directed behavioral adaptations of the current relationship between the individual and the environment by the perception of the unfolding invariants). Hence, we may hypothesize that the previously mentioned perceptual attunement to invariants (in this case, the tau information) could be lower and that this could be demonstrated, for instance, in a more variable and less correlated relationship between the tau variables of the approach and pass related ones. Besides, as some authors have empirically demonstrated information is scaled to the action capabilities of the perceiver/actor (for reviews see Fajen et al., 2009; Montagne, 2005), so we may assume that different levels of expertise will correspond to different relations between perceptual variables and action variables.

Pinder, Renshaw, and Davids (2009) recently claimed that to attune perception to invariants, these specifying variables must be available to the actor, something that is not often assured in more abstract experimental set-ups. In the same way, Bootsma and van Wieringen (1990) in their study investigating the perceptual guidance of an attacking forehand drive in table tennis, stated that ‘‘experiments in which subjects operate under real-life conditions can be logically expected to render a more thorough insight into the way behavior is coordinated with events in the environment’’ (p. 22). Therefore in our study, involving the observation and analysis of rugby players while performing in an actual game that incorporates realistic changing dynamics of the player–environment system gives a useful insight into the understanding of the coupling between perception and action that express decisions.

Since information is viewed as having a lawful relation with action, Araújo et al. (2006) emphasized the importance of identifying the informational variables in order to understand the control laws and how they shape decisions expressed in the course of action, i.e., transitions in the player’s course of action. The present study was designed to further this area of research and showed how the variables available in the interaction between players and the environment in an actual game significantly correlated with the type of pass that emerged. This line of work should be considered for further research and/or practical applications in the construction of representative designs either in research (in the design of experimental tasks), or practice (to define practice task constraints) to study/develop the coupling of perception and action.

Future research will engage a deeper analysis of the evolving performance dynamics of each situation and the inclusion of other potential informational variables in order to better understand this phenomenon. It would be of particular interest that further studies include not only the gap between first receiver and the nearest defender, but take also into account the gap between the second receiver and the correspondent nearest defender, as well as the gap between both attackers in order to assess the coordination in the tau guidance of behavior between these players (tau-couplings). In summary, this study may be regarded as providing evidence that action is anticipatory and guided towards future states. In this study we showed how the variable tau is being used as an informational variable that pushes or constrains rugby pass decisional behavior.

4.6. Acknowledgment

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Chapter 5

Changes in task constraints shape decision-making behaviours of team games players [4]

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5. Changes in practice task constraints shape decision-making behaviours of team games players

5.1. Abstract

This study examined the effects of manipulating relative positioning between defenders (initial distance apart) on emergent decision-making and actions in a 1 vs. 2 rugby union performance sub-phase. Twelve experienced youth players performed 80 trials of a 1 (attacker) vs. 2 (defenders) practice task in which the starting distance between defenders was systematically decreased. Movement displacement trajectories of participants were video recorded to obtain 2D positional data. The independent variable was the starting distance between defenders and dependent variables were: (i) performance outcome (try or tackle), (ii) mean speed of all players during performance, and (iii) time between the first crossover and the end of the trial. Repeated measures ANOVA was used to compare the effects of different starting distances on performance. Shorter starting distances between defenders were associated with a higher frequency of effective tackle outcomes, lower mean speeds of all participants, and a greater time period between the first crossover and the end of the trial. Decision-making behaviours emerged as a function of changes in participants' spatial location during performance. This observation supports the importance of manipulating key spatial-temporal variables in designing representative practice task constraints that induce functional player–environment interactions in team sports training.

***Keywords*:** Task constraints; Representative design; Decision-making behaviour; Team games; Rugby union.

5.2. Introduction

Ecological dynamics research in sport has demonstrated that decision-making behaviours continually emerge from interactions between players and their surroundings [1,2]. From this perspective, emergent decision-making behaviour has been conceptually defined as transitions in the action paths of performers [3]. Action path selection is guided by information on relevant properties of the performance environment [1,4], and decision-making can be investigated through observing the behavioural dynamics of individual performers [5,4]. Ecological dynamics considers the performer and the environment as mechanically and informationally coupled, with a need to probe the functional patterns of behaviour emerging from each individual athlete's interactions with the structured performance environment over time [1,4].

Contextual constraints on behaviour may change the way that information is used by individuals [6,7]. According to Juarrero [8], human behaviour is influenced over time by first- and second-order constraints. First-order constraints are initial task conditions (e.g. field boundaries, number of players, initial positions, targets and aims) that decrease complete randomness in behaviour by bounding the functional decisions and actions that emerge from performers [2]. During practice tasks which are intended to simulate performance conditions, these constraints tend to define the players' initial intentions as they explore performance contexts. In this way, they lead the goal-directed interpersonal interactions between performers. Decreasing interpersonal distances between performers that characterise coordination tendencies in team sports leads to the emergence of second-order constraints on behaviour. During different performance sub-phases, decreasing interpersonal distances of attackers and defenders lead to the emergence of context dependency, meaning that the actions of one performer constrain and are constrained by the actions of significant others. This context dependency is characterised by the relative positioning and speed of participants within low values of interpersonal distance. Under this type of second-order constraints, interactions between performers can change to structurally different forms as a single key system parameter changes in value (e.g. changes in the relative velocity between performers [2]). For instance, when a tackle occurs in the team sport of rugby union, players' interactions can change from an informational to a physical coupling. These second-order constraints bound each performer's decisions and actions by removing behavioural independence and increasing contextual dependency. However, changes in system parameter values only become crucial when attackers and defenders form dyadic systems in critical performance regions [2,9]. These regions emerge in space and time due to contextual dependency of performers. Within those regions, system structural organization (e.g. 1 vs 2 sub-system) becomes sensitive to any small near-neighbour interactions and system transitions may occur [9,10].

Studies by Passos and colleagues [2,9] on 1 vs 1 rugby union performance sub-phases identified critical values of relational variables that induced one of three possible system states (i.e. effective tackle by the defender, ineffective tackle, or a try being scored by the attacker). This work, in line with theoretical predictions in ecological dynamics [11,12,13], clearly revealed the importance of studying effects of second-order constraints on behaviours in attacker-defender dyads.

Observations of competitive performance in team sports have revealed how attacking or defensive players work to create a numerical advantage. Changes in space available on the playing field create action possibilities (e.g. for a player to run past the defensive line or to tackle an opponent) in the pursuit of performance goals (e.g. to reach the try line or to recover ball possession). Here we studied the 1 vs 2 sub-phase in the team sport of rugby union to investigate how first-order constraints, such as players' starting positions, and pitch boundaries might interact to shape emergent decision-making and action during performance [9]. Our aim was to examine whether manipulating the starting locations of the two defenders changed their decision-making behaviours expressed by their movement displacement trajectories towards the attacker. We also sought to understand how these initial task constraints might influence attacker-defender systems captured by transitions in performance outcomes.

5.3. Method

Participants were 12, youth-level male rugby union players under 18 years of age (17.33 ± 0.49 years) with nearly four years competitive experience (3.91 ± 1.97 years). Participants provided voluntary and informed parental consent and all experimental procedures were conducted in compliance with a local university's ethical guidelines.

The representative experimental task [14] consisted of a practice task simulating a common 1 vs 2 sub-phase of play in rugby union wherein defending players had a numerical advantage over a lone opponent near the try line. The performance goal for the attacker was to score a try, with the two defenders attempting to prevent it by tackling him within the laws of the game. The task was undertaken in a 20 m (width) x 10 m (depth) performance area. The try line corresponded to the line where the defenders were initially located (see Figure 5.1). The starting distance between defenders was systematically manipulated in a decreasing sequence ranging from 20 m to 2 m (in decrements of 2 m) to test the influence of initial task conditions on performance [15]. The starting distance between the attacker and the try line (where the defenders were positioned) was 10 m in all trials. Prior to the experimental trials, participants performed warm-up exercises under the supervision of their coaches.

Before each trial, the attacker faced away from the defenders at the starting location, and the defenders started in a pre-defined space near the try line. Defenders were instructed where to start the 1 vs 2 task. After a signal from the experimenter, the participants started performing the 1 vs 2 task. No specific instructions were provided regarding the movement trajectories that the attacker or defenders were to take, thus preserving the emergent nature of decisions and actions. There were also no limitations set on the time available to perform the task beyond the natural time constraints imposed by the opposing participants' actions. It was observed that, in all trials, attackers tried to reach the try line as soon as possible to avoid being tackled by defenders (duration of trials: 3.55s ± 0.95).

Of the twelve participants, four performed the task as attackers and eight acted as defenders. Each attacker performed the 1 vs 2 trials twice at each of the ten different values for the defenders' starting distances. To avoid fatigue effects on performance, participants performed only one trial at a time and recovered after completing each 1 vs 2 situation. The pairs of defenders were also randomly assigned. Thus, between each trial each participant rested for at least 1 min, maintaining a work/rest ratio of approximately 1/7. Each attacker and defender performed a total of twenty 1 vs 2 trials (2 repetitions x 10 different defenders' starting distances). The entire experiment comprised a total of eighty 1 vs 2 trials.

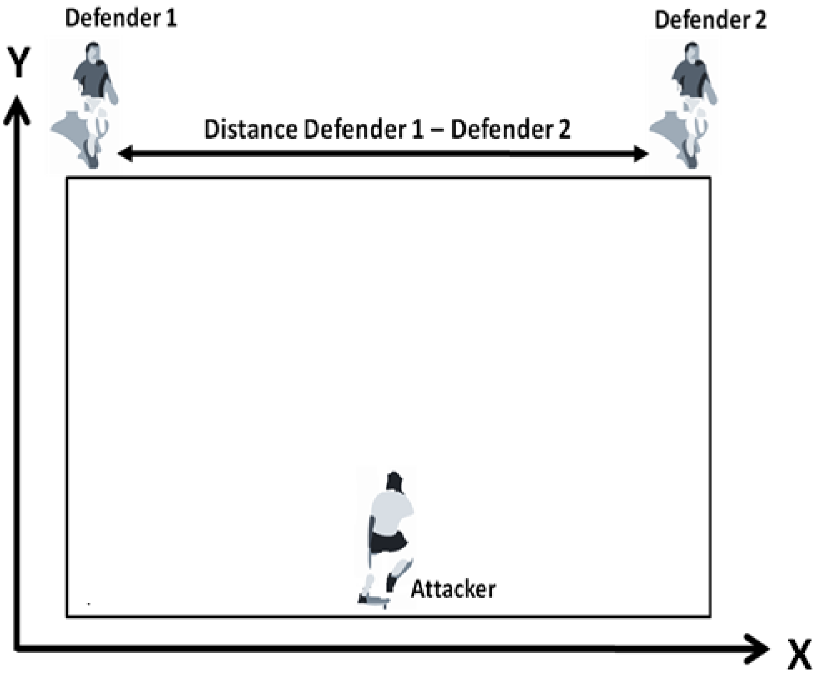

Figure 5.1. A schematic representation of the 1 vs 2 experimental task. Outlined is the manipulated starting distance between defenders (Distance Defender 1 – Defender 2).

Performance in all trials was recorded by a digital video camera (25 Hz) located in a transversal (approximately 45˚ and elevated plane (about 4 m high) relative to the performance field. Video image was digitised using TACTO 8.0 software [16,17] that showed an accuracy higher than 95% using 25 images/s [18]. The digitisation procedures consisted of playing the video recordings in slow motion (1/2 normal velocity) on a computer, and following a selected working point with the mouse cursor. The selected working point was the middle point between the feet of each participant, as this is regarded as a projection of the individual's centre of gravity on the ground [19]. This software allowed the 2D virtual coordinates (measured in pixels) for *x*- and *y*-components of movement displacement trajectories of participants to be obtained. To transform the virtual into field spatial coordinates (expressed in meters) the mathematical procedure of Direct Linear Transformation (2D-DLT) was applied [19] and data were filtered using a Butterworth low-pass filter with a cut-off frequency of 6 Hz for all trials [19]. MATLAB software (MATLAB 2008a, MathWorks™) was used for all computation steps, including the calculation of kinematic variables (i.e. some of the dependent variables). The dependent variables were: trial outcome, each participant's mean speed, trial duration, and time between the first crossover and the end of the trial. A first crossover was defined as when an attacker's longitudinal distance to the try line became shorter than the same value for a defender (identifying the first defender to reach the attacker). The end of the trial was defined as the instant that the trial ended due either to a successful try being scored or an effective tackle made. Performance outcome measures for each trial (a successful try or an effective tackle), were recorded based on the participants' end *y*-coordinate values. A successful try was recorded whenever the y-coordinate data corresponding to the attacking participant coincided with the try line y-coordinate. An effective tackle was recorded whenever the y-coordinate of the attacker remained smaller than the y-coordinate defining the try line (i.e. due to the attacker not being able to move to the try line with the ball after an effective tackle by at least one of the defending participants).

After considering the normality and homogeneity nature of the data, we used a one-way repeated measures ANOVA to examine mean differences in dependent variables across all the starting distances between defenders, using SPSS® 17.0 software (SPSS Inc., Chicago, USA). Statistical significance level was maintained at 95% ($p < 0.05$). Due to the large number of levels of the RM variable (i.e. the 10 levels corresponding to the 10 manipulated starting distances between the defenders), Mauchly's test was used to consider violation of the sphericity assumption, and the Greenhouse-Geisser correction for the degrees of freedom was implemented [21]. Bonferroni's post hoc tests were used to identify the location of specific effects.

5.4. Results

Frequency analysis of the two possible performance outcomes (i.e. successful try or effective tackle) emerging at different values of the manipulated starting distance between defenders, were used to identify system transitions (see Figure 5.2). A higher frequency of try outcomes emerged at higher values of starting distance between defenders (i.e. 20 m to 10 m) that transited to a higher frequency of effective tackles when starting distance was reduced to 8 m. This transition in the frequency of performance outcomes (tries to tackles at 8 m of the manipulated distance) was followed by another transition to a higher frequency of tries being scored (at 6 m). This observation suggests that two possible system states coexisted for the different values of starting distance between defenders (8 m and 6 m). At the lowest values of the starting distance between defenders (4 m and 2 m) a higher frequency of effective tackles was verified. Mean scores of successful tries and effective tackles significantly differed across variations in starting distances (*F* (4, 28) = 3.87, *p* = 0.012).

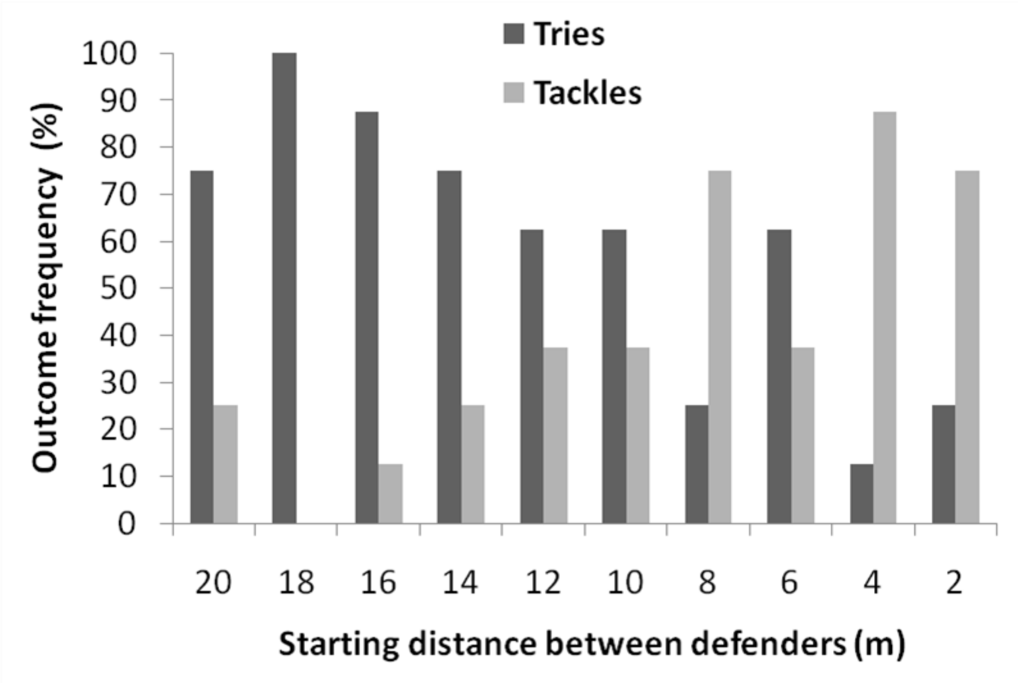

Figure 5.2. Trials outcome histogram – try or tackle – over each value of the scaled starting distance between defenders. The bars value (vertical axis) determines the percentage (%) of occurrence. The categories (horizontal axis) concern the distance from which the defenders started the task in the correspondent sequence of change.

Analysis of participant movement displacement trajectories during each trial revealed changes in the displacement trajectories of defenders as a function of the manipulated starting distance (Figure 5.3A). When defending participants started the task located further apart from each other, they tended to move closer together and wait for the attacker near the try line (i.e. they tended to move laterally across the try line instead of forward in the direction of the attacker). Conversely, as the starting distance between defenders was decreased, they tended to run forward in the direction of the attacker moving away from the try line (i.e. decreasing the distance to contact the attacker). These observed changes in movement displacement trajectory were revealed in the participant speed profiles. Significant differences in mean speed occurred for both attacker and defenders as a function of the manipulated starting distances between defenders (Attacker: F (6, 42) = 8.19, $p \leq 0.001$; Defender 1: F (4, 26) = 2.55, $p \leq 0.017$; Defender 2: F (9 4, 30) = 3.53, $p \leq 0.001$). As Figure 5.3B shows, smaller starting distances between defenders were associated with lower mean speeds of the three participants.

Bonferroni's post hoc tests revealed significant decreases in the mean speeds of attackers between 20 m (7.99 ± 1.84) and 4 m (4.48 ± 0.72, $p \leq 0.02$) and 20 m and 2 m of the defenders' initial starting distances (4.99 ± 0.83, $p \leq 0.05$). Follow-up tests also revealed significant decreases in the first defender's mean speed between 20 m (5.25 ± 0.73) and 8 m (4.22 ± 0.90, $p \leq 0.05$) of starting distances, and in the second defender's mean speed between 20 m (5.75 ± 1.09) and 6 m starting distances (3.86 ± 0.53, $p \leq 0.05$).

In all trials at least one of the defenders was passed by the attacker before the end of the trial, and data on the period of time between the occurrence of the first crossover and the end of the trial are displayed in Figure 5.3C. Statistical analysis revealed that the time period between first crossover and the end of the trial was significantly greater for lower values of the starting distance between defenders (F (3, 21) = 3.01, $p \leq 0.05$). The total duration of trials remained stable regardless of the manipulated starting distances between defenders (F (3, 22) = 2.10, $p > 0.05$). The data from these two variables reflected the changes in movement displacement trajectories made by defenders as starting distance was manipulated (see Figure 5.3A).

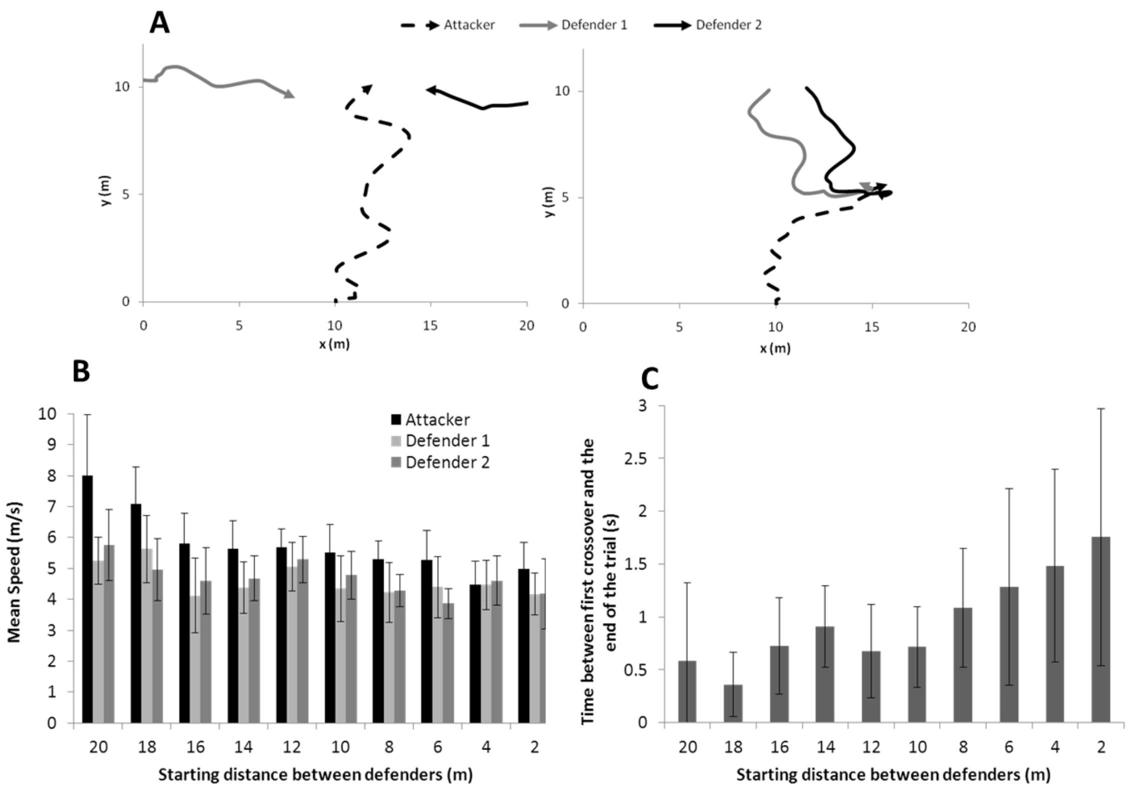

Figure 5.3. A (upper panel): Exemplar trials of participants' displacement trajectories in the two extreme values of the manipulated starting distance between defenders. Left panel is a trial performed with the greatest value (i.e., 20 meters) and in the right panel a trial performed with the smallest value (i.e., 2 meters) of the manipulated distance. B (middle panel): Mean and standard deviation of speed of participants' displacement trajectories for the decreasing values of the starting distance between defenders, for all trials. C (lower panel): Mean and standard deviation of the time period between first crossover and the end of the trial for the decreasing values of the starting distance between defenders, for all trials.

5.5. Discussion

In this study we sought to investigate how the starting distance between defenders might influence decision-making behaviours and actions of an attacker-defender sub-system captured by transitions in performance outcomes (try or tackle). We observed two possible state outcomes which coexisted for trials performed with the defenders starting apart from each other at a distance of 8 m and 6 m. This observation may be analogous to the feature of bistability in nonlinear systems [22] by demonstrating how two specific state outcomes might emerge under specific task constraints, supporting previous research findings. For example, in a study on boxing, Hristovski and colleagues [23] showed the emergence of specific punching actions as a function of changes in a key task constraint: the scaled boxer-target distance. In their study, coexisting action modes were observed at equal values of the scaled boxer-target distance (demonstrating system multistability [23,24]). Under the representative task constraints of 1 vs 2 attacker-defender interactions in the team sport of rugby union, coexisting state outcomes were observed at specific starting distances between defenders, likewise revealing bistability in this particular sub-system. Numerical advantage for the defending participants may have been expected to increase the likelihood of an effective tackle emerging in this sub-phase. However, analysis of frequency data on performance outcomes at critical values of starting distances between defenders, suggested that this numerical advantage was mediated by their initial positioning.

Previous studies have demonstrated the influence of second-order constraints on behaviour of rugby union attacker-defender dyads, identifying critical values where changes in key relational variables (e.g. participants' running line speed) influenced system outcomes [2,9]. Within critical values of these key relational variables a higher contextual dependency of performers was observed. System structural organization heightened in sensitivity to any slight near-neighbour interactions and sudden transitions, such as an attacker outrunning a defender, could arise [9,10].

In a similar vein, our findings suggested that first order constraints (like the manipulated starting distance between defenders) revealed, not only critical values at which 'outcome bistability' emerged, but also specific values at which one of the two possible outcomes became more prevalent.

Results also showed changes in participant behaviours, such as the defenders' action path selection (movement displacement trajectories), mean speed during displacement, and the time between a crossover and the end of each trial, as starting distances were manipulated. Despite no explicit instructions, when defenders started further apart, they tended to first run towards each other, aiming to close the gap and acquire a functional interpersonal distance required to face the attacker as a collective sub-unit [25]. When defenders started closer together, a higher frequency of forward displacement trajectories emerged, which was consistent with the first principle of field invasion games like rugby union game (i.e. to advance in the field).

Additionally, when the starting distance between defenders decreased, lower mean speeds of displacement trajectories emerged in both defenders and attackers.

There was also a longer time between the attacker passing the first defender and the trial termination (i.e. the instant a try was scored or an effective tackle made by the second defender). These results revealed how emergent behaviours of participants were influenced by changes in informational constraints [6], specifically by the first-order contextual constraints [8,9] captured by the starting distances between defenders. These findings concur with the views of Passos et al. [9] that first-order constraints boost the probability of emergence of specific decisions and actions in team sports.

The results also support Warren's [4] stance on behaviour not being stereotyped and rigid but instead flexible and adapted in a goal-directed manner to emerging environmental conditions or task demands. These data showed that behavioural dynamics in social neurobiological systems emerge from local interactions between system agents (in the case of team games, the players) and between the players and the environment guided by the unfolding information for action provided by defender-attacker-environment system [4,5]. The modification of the defenders' actions, as a function of their varying starting distance apart, suggested that action possibilities for these players may be understood in terms of stable states of this system's dynamics. Action paths developed by players are viewed as a process guided by the changes in spatial-temporal information defined by the relative positioning between the players [1,4]. At specific values of the scaled starting distance (first-order constraints), both performance outcomes were recurrent and particular behavioural solutions emerged (exemplified in the defender's movement displacement trajectories). These variables seem to express different preferred relational states of this attacker-defender system. Despite the compelling nature of the data, some caution is recommended due to the small number of trials performed by each participant at each manipulated starting distance. Further work is needed to confirm these findings with a larger sample of performance trials and varying skill levels.

5.6. Conclusion

This study shed light on how practice task design, involving simple manipulations such as different distances between players, significantly influenced the emergent behavioural dynamics in team games. The data indicate that practice simulations can be designed to intentionally control the way in which such variable manipulations could result in specific emergent behaviours. Particular initial conditions (such as the starting distance between defenders) can increase the likelihood of distinct performance outcomes, ensuring that these outcomes are practiced by learners. Stable sub-phase outcomes, such as a decreasing frequency of try outcomes (or conversely tackle outcome) can emerge with manipulation of key variables such as the starting distance between defenders. Although game-based training may provide the emergence of opportunities to practice try-scoring or try-prevention behaviours, identification and manipulation of key spatial-temporal variables by coaches can increase the frequency with which these specific functional behaviours can emerge in practice. Considering practice tasks as simulations of the performance environment, coaches and sport scientists need to identify the spatial-temporal variables that make specific simulations more faithful. The manipulation of particular critical values of key variables can provide information for action to enhance practice specificity and promote performers' adaptations within critical performance regions.

5.7. Practical Implications

- Participant behaviours are flexible and adapted in a goal-directed manner to current task constraints.
- Simple practice task constraint manipulations, such as varying number of players involved, distances between players (e.g. defender-defender initial conditions) and field dimensions, powerfully influence emergent decisions and actions of performers (attackers and defenders) in team games.
- Coaches and scientists need to identify the specific spatial-temporal variables that, by manipulation in practice, make simulations of the performance environment more faithful.
- Training tasks must be designed to allow performers to exploit functional, adaptive movement behaviours which emerge under constraints.

5.8. Acknowledgments

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5.9. References

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Chapter 6

Perceiving and acting upon spaces in a VR rugby task: expertise effects in affordance detection and task achievement [5]

[5] Submitted as:
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6. Perceiving and acting upon spaces in a VR rugby task: expertise effects in affordance detection and task achievement

6.1. Abstract

This study used a virtual simulated 3vs3 rugby task to investigate whether gaps opening in particular running channels promote different actions by the ball-carrier player and whether an effect of rugby expertise is verified. We manipulated emergent gaps in three different locations: gap1 in the participant’s, gap 2 in the 1st receiver's, and gap3 in the 2nd receiver's running channel. Recreational, intermediate, professional and non-rugby players performed the task. They could i) run with the ball, ii) make a short pass, or iii) make a long pass. All actions were digitally recorded. Results revealed that the emergence of gaps in the defensive line with respect to the participant significantly influenced action selection. Namely, ‘run’ was most often the action performed in gap 1, ‘short pass’ in gap 2, and ‘long pass’ in gap 3 trials. Furthermore, a strong positive relationship between expertise and task achievement was found.

Keywords: perception-action coupling, affordance, decision-making, expertise, team sport, rugby union.

6.2. Introduction

In order to better understand successful performance in team sports one must consider the perception of action possibilities emerging from players' interpersonal interactions. The aim of this study was to investigate which action possibilities are perceived and executed (from the perspective of the ball-carrier) in a typical three-versus-three (3vs3) rugby scenario where the changing position of the defenders results in emerging gaps or 'spaces' in different running channels of the defensive line. More specifically, we wanted to see how the location of an opening gap with respect to the ball carrier, influenced the action selection. Furthermore, we also wanted to see how action selection differed with levels of rugby expertise.

In rugby union, as in any team sport, game cooperation and competition for space co-occur throughout the game. For instance, the player who is the ball-carrier is constantly looking for spaces in the defensive line through which he/she or a teammate can run so as to get nearer to the try line. In terms of action possibilities (or affordances, Gibson, 1979), the ball-carrier can run, pass or kick the ball to gain some kind of territorial advantage. Affordances (Gibson, 1979) are a key concept for this study. They imply a mutual and reciprocal relationship between the individual and the environment in which he/she is acting and are taken with reference to the individual's body scale and particular action capabilities (see Fajen, Riley, & Turvey, 2009, for a review in sport). As follows, decision-making in sport may be regarded as a goal-directed process of acting on the affordances available in the performance environment (e.g., Araújo, Davids, & Hristovski, 2006).

Empirical research on the affordance of passing through apertures (Warren & Whang, 1987) has demonstrated that successful behaviour is a matter of perceiving affordances in an attuned fashion (Fajen & Turvey, 2003). As stated by Fajen and Turvey (2003) "a narrow opening may afford passage by a small child, but not by a large adult; a narrower opening may afford passage by a cat but not by a small child" (p. 277). Likewise, for an attacker in rugby union the reception of a ball may offer him/her the opportunity to run to score a try if a sufficient gap in the defensive line is perceived. Accordingly, successful decision behaviour from this perspective rests on the ability to perceive which goal-directed actions are possible (Fajen & Turvey, 2003; Turvey, 1992).

Information is directly related to affordances, since to perceive an affordance is to perceive the information specifying it (Gibson, 1979). Players in team sports are surrounded by abundant sources of energy arrays that convey information that shapes decision-making and action during goal-directed activity (Davids, 2009). As follows, the information that is available in changing spaces in the defensive line may be perceived by a ball-carrier as offering two general action possibilities. The ball-carrier either perceives it as passable and runs through the perceived defensive gap, or as not passable and kicks the ball or passes it on to a teammate. Actions may be thus regarded as categorical and the boundaries separating different categories may be defined by the player-environment fit (Fajen & Turvey, 2003) as scaled by his/her body and action capabilities (Araújo, Davids, Chow, & Passos, 2009; Turvey & Shaw, 1995).

The consistent successful behaviour often demonstrated by experts illustrates the improved fit of the relation between the player and the performance environment (Araújo et al., 2009; Jacobs & Michaels, 2007), in terms of the adaptive and functional relationship they establish (Araújo & Davids, 2011; Araújo, Davids, & Serpa, 2005; Jacobs & Michaels, 2007). Expertise in team sports must therefore be considered in terms of the player-environment system (Turvey & Shaw, 1995) and should ideally be assessed by upholding natural perception-action interactions (e.g., Araújo et al., 2009).

In an attempt to do this, the present work looked at a 3 vs 3 rugby union task in a virtual environment where realistic simulations of attackers versus defenders were reconstructed. The study had two main objectives. Firstly, to investigate how the affordance of opening gaps offers different action opportunities to players, independent of their level of expertise. Secondly, to show how rugby expertise influences action selection in terms of both affordance perception and task achievement.

6.3. Methods

6.3.1. Participants

Forty six participants (n = 46) took part in this experiment and were divided into four groups: non-rugby players (n = 9; M_{age} = 26.63 years, SD = 2.97), recreational (n = 9, M_{age}= 26.00 years, SD = 7.35), intermediate (n = 16, M_{age} = 26.56 years, SD = 4.10) and professional (n = 12; M_{age} = 20.33 years, SD = 1.15). The study had full ethical approval and all participants gave informed written consent and filled in a questionnaire regarding their sports experience, specifically relating to competitive rugby engagement.

The criteria used to define the level of expertise were set according to the reported number of years of competitive rugby practice and current level of engagement in the activity. Accordingly, a non-rugby group included participants who were familiar with the elementary rules of rugby, but who had never played rugby before. The players in the recreational group had on average 5 years of competitive rugby experience (M = 5.44 years, SD = 4.66), with experience being limited to a lower regional level, and no international experience. Players in the intermediate group had on average 13 years rugby experience (M = 12.94 years, SD = 4.27), playing at both regional and national level, and at a superior league level. The professional group had on average 13 years rugby experience (M = 12.50 years, SD = 1.51) playing at both regional and top national level, with all players having some form of experience in international competition. It is important to note that they were full time professional rugby players within the only professional national rugby team (Ulster Rugby, Northern Ireland) which competes in European competitions. All participants were not familiar with the specific virtual reality simulation used and all performed exactly the same tasks.

6.3.2. Task

The experimental task consisted of a virtual simulated 3vs3 rugby situation. Participants performed the task individually from the perspective of the ball-carrier (attacking player) while carrying a real ball in their hands. Participants wore a head mounted display unit (HMD) (Cybermind Visette, 60 Hz, 45^{o} diagonal field of view) with a control box mounted in a back pack also carried by the participants (Figure 6.1). A wireless Intersense head tracker (Intersense 900 MicroTrax 6-DOF tracker) attached to the top of the head set and two wireless hand trackers attached to a pair of rugby gloves allowed for the capture of the position and orientation of the head and both hands (at a rate of 80Hz approximately) in the virtual environment, respectively. The position of the head tracker controlled the viewpoint in the virtual environment in real-time with a latency of 4ms between movement and visualization (created using

3DVia Virtools 4.1). It is important to note that movement in the real world corresponded to the same amplitude of movement in the virtual space. This equipment gave participants the impression of being on a standard rugby pitch (70m x 144m) inside a stadium. Participants could see three defenders in front of them (see Figure 6.1A), two teammates to their right or left hand side (according to their preferred side for passing) (see Figure 6.1B). Running motion of these virtual players (i.e., defenders and teammates) was obtained by motion capture (Qualisys Oqus) of a rugby player making a straight run. This motion capture was then converted into a animation loop and imported into the virtual environment (Autodesk Motionbuilder and 3DS Max 2011) where it was used to animate all virtual characters movement. This meant that all virtual players were of identical build and height, and ran likewise (i.e., the same run animation). Virtual depictions of the participant's hands were also visible in the virtual environment and corresponded to the real relative position and orientation of the hands with respect to the head. As real hand movements controlled the movement of the virtual hands presented in the HMD, the sense of presence was heightened by the combination of the visual (virtual) and haptic (real) sensations of hand movement.

During the 3vs3 trials defenders moved towards the attacking line and participants (taking the perspective of the ball-carrier) were able to perform the task as if they were in the real rugby situation but were instructed to avoid contact. The goal of the task was to break the defensive line, yet avoid contact with the opposing players. To succeed, participants have to exploit the space between defenders. The ball-carrier can do this by running through a gap in his/her own channel, or passing the ball to one of the two teammates who could exploit a gap further along the defensive line. A pass made to the first teammate was classified as a short pass and a pass made to the second teammate as a long pass. Kicking was not allowed primarily for safety reasons and to force the players to exploit gaps in the defensive line rather than the space behind the defensive line.

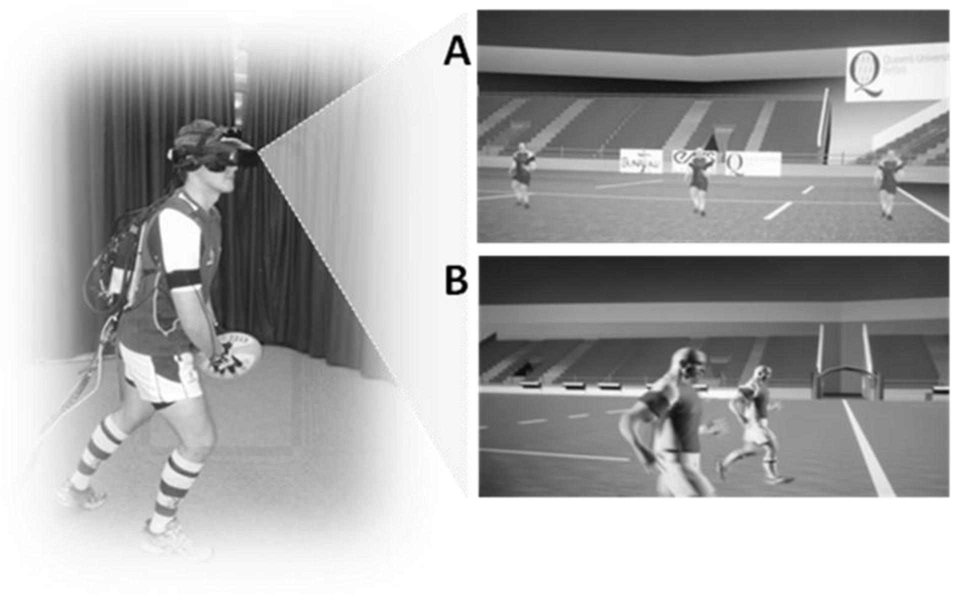

Figure 6.1. The immersive interactive Virtual Reality Apparatus. The panel on the left shows a participant wearing the head mounted display (HMD) with attached head tracker along with the back pack that housed the control unit. The players also wore a pair of rugby gloves onto which two hand trackers were attached. Panel A illustrates what the players could see in front of them (i.e.the defensive line) and panel B shows what they could see if they turned their head to the left or the right, i.e., the position of their teammates (first and second receivers).

6.3.3. Design and procedure

The 3vs3 virtual simulated task had as fixed conditions the starting positions of attackers (ball-carrier participant, and the two teammates) and the three defenders, the total forward distance covered by the defenders and the speed with which they ran (i.e., 20 m in depth at 10m/s), and thus the time defenders took to reach the attacking line (2.0 s). Each dyad of attacker and marking defender was positioned in a corresponding running channel (see Figure 6.2). A trial ended when defenders reached the attacking line. As regards the changing experimental conditions, opening gaps were manipulated in specific running channels which gave rise to three gap locations (see Figure 6.2). As the attacking and defending players were initially aligned, each gap location was defined by manipulating the running angle of the defender in a particular channel, whilst keeping the running angles of the remaining two defenders constant. By changing the running angle the defender would end up at an end position that was 1 metre away from where he would have been if he had ran towards the attacking player in a straight line. The three different gaps that opened during the unfolding action were located in the participant's own running channel (Gap 1), the first teammate's running channel (Gap 2), and the second teammate's running channel (Gap 3) (Figure 6.2). In addition, we also presented a 'no gap' condition (neutral condition) where all defenders ran in a straight line towards the attackers (i.e., no gap opened in any of the running channels).

Each participant was randomly presented with the four conditions (3 gap and 1 control) a total of six times each giving rise to 24 experimental trials. All of the players performed the experiment so that any pass made would be to their preferred side (information requested from the participants prior to the experiment commencing). Actions performed by the participants in each of the trials was identified by the experimenter and corroborated a posteriori by the participant as: run, short or long pass. Importantly, it was made explicit that this was merely a procedure to validate the identified action and did not provide any feedback. That is to say the participants did not know if the particular action they performed was the action that was expected for that given condition. The accuracy of the pass was not considered as it was not within the remit of this study.

A prior familiarization period was carried out so as to allow the participants to become accustomed to the HMD, explore the virtual rugby environment, and become familiar with the task (namely, to respond - run or pass- in real time to the advancing defensive line).

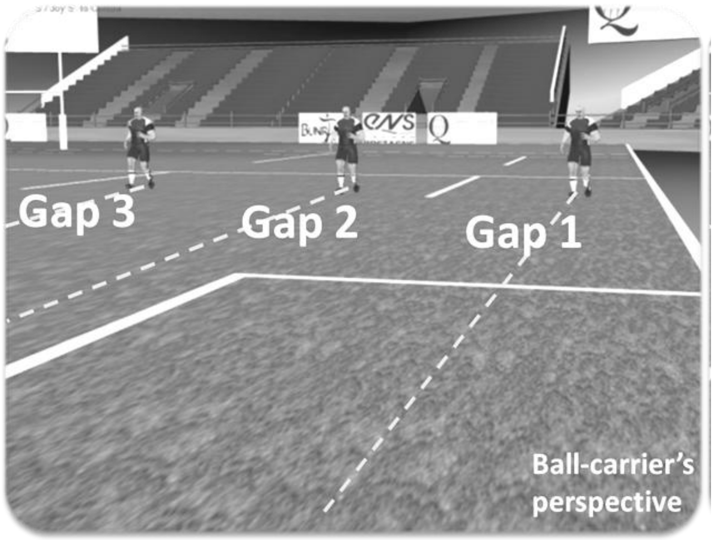

Figure 6.2. Scheme of gap conditions. Each gap location is defined by varying the running angle of the defender in a specific running channel. Gap 1: located in participant's own running channel. Gap 2: located in the running channel of the first receiver. Gap 3: located in the running channel of the second receiver.

It is important to note that the design of this experiment was based on a previous pilot field study performed with professional players from the Ulster rugby team. Although the players in the pilot study are from the same professional squad of players, they did not participate in the main experiment. In the pilot study a 3vs3 rugby task was performed where one defender was instructed (unknown to the attackers) to change his running angle so that a gap would 'open' between players. The actions chosen by the attackers based on the running angles of the defenders informed the parameters selected for this study. The 'backs' coach of this professional team was also asked what a ball-carrier would 'typically' do when confronted with gaps opening in different running channels. The illustration in Figure 6.2 shows that a gap opening in a participant's own running channel (Gap 1) would offer a running action, a gap opening in the first receiver's running channel (Gap 2) would afford a pass from the ball carrier to that teammate (i.e., a short pass) and finally a gap opening in the second receiver's running channel (Gap 3) would afford a pass from the ball carrier to that teammate (i.e., a long pass).

6.4. Results

6.4.1. Action Performed

To investigate the relationship between expertise (Group), the location of the opening gaps plus the no gap condition (Gap), and the action performed a 4 x 4 (Group x Gap) multivariate analysis of variance (MANOVA) was conducted with each of the three classified actions (run, short pass, and long pass) as dependent variables. Statistics used to test significance of main effects and interaction were Wilks's lambda (LRATIO) and Bonferroni post hoc tests. Statistical significance was set at $p < .05$ level.

6.4.1.1. Gap location effects in the Action performed

The location of the gaps was found to significantly influence the action that was performed (LRATIO = 38.438, $p < .001$, $\eta 2_p = .408$) (see table 1). This was manifested in the running action being significantly more frequent for Gap 1 (M = 87.68, SD = 25.20) when compared to No Gap (M = 31.88, SD = 29.78), Gap 2 (M = 28.99, SD = 27.09), or Gap 3 (M = 28.26, SD = 27.41) conditions ($p <.001$ - see Figure 6.3A).

As regards to the short pass action, this was significantly more frequent in Gap 2 (*M* = 64.49, *SD* = 31.94) when compared to the No Gap (*M* = 35.14, *SD* = 23.63), Gap 3 (*M* = 25.72, *SD* = 27.38), or Gap 1 (*M* = 2.54, *SD* = 7.83) conditions ($p < .001$- see Figure 6.3A).

Finally, the long pass action was significantly more frequent in Gap 3 (*M* = 46.01, *SD* = 35.86) when compared to No Gap (*M* = 32.97, *SD* = 24.97), Gap 1 (*M* = 9.78, *SD* = 21.82), and Gap 2 (*M* = 6.52, *SD* = 13.37) conditions ($p < .001$- see Figure 6.3A).

6.4.1.2. Expertise effects on the Action performed

A significant main effect for Group (LRATIO = 2.573, $p = .019$, $\eta2_p = .044$), was found but only for the running action (see table 1). The post-hoc tests (see Figure 6.3B) indicated that the running action was significantly more frequent in the recreational group (*M* = 56.02, *SD* = 35.89) compared to the professional group (*M* = 34.72, *SD* = 40.22) groups ($p = .001$). Although the recreational group was higher than the non-rugby (*M* = 48.15, *SD* = 32.56) and intermediate (*M* = 42.45, *SD* = 36.36) groups, these differences were not significant ($p > .05$).

For the short pass professional players (*M* = 36.46, *SD* = 37.13), non-rugby players (*M* = 30.09, *SD* = 24.18) and intermediate players (*M* = 33.59, *SD* = 34.82), performed this action more frequently than recreational players (*M* = 25.00, *SD* = 30.99), though this was not found to be significant.

The long pass action was more frequent amongst the professional players (*M* = 28.82, *SD* = 34.85) compared to the non-rugby (*M* = 21.76, *SD* = 23.17), the intermediate (*M* = 23.82, *SD* = 31.83) or the recreational group (*M* = 18.98, *SD* = 25.56). However, these differences were not found to be significant.

Table 6.1. *Effects of a multivariate analysis of variance (MANOVA).*

	Run			**Short Pass**			**Long Pass**		
Effect	*F*(3,168)	*p*	$\eta2_p$	*F*(3,168)	*p*	$\eta2_p$	*F*(3,168)	*p*	$\eta2_p$
Gap	50.196	<.001**	.473	50.021	.000**	.472	22.629	<.001*	.288
Group	5.162	.002*	.084	2.051	.109	.035	1.332	.266	.023
Group x Gap	2.669	.006*	.125	5.053	.001*	.213	4.217	.001*	.184

Note: * $p < .05$. ** $p < .001$.

Although each gap condition made up a quarter of the total trials performed, the action performed was not equally distributed across groups. It is interesting to note that frequencies of run, short pass, or long pass actions performed by the professional group across all experimental conditions were closest to the expected experimental ratio (i.e., about 33.33%).

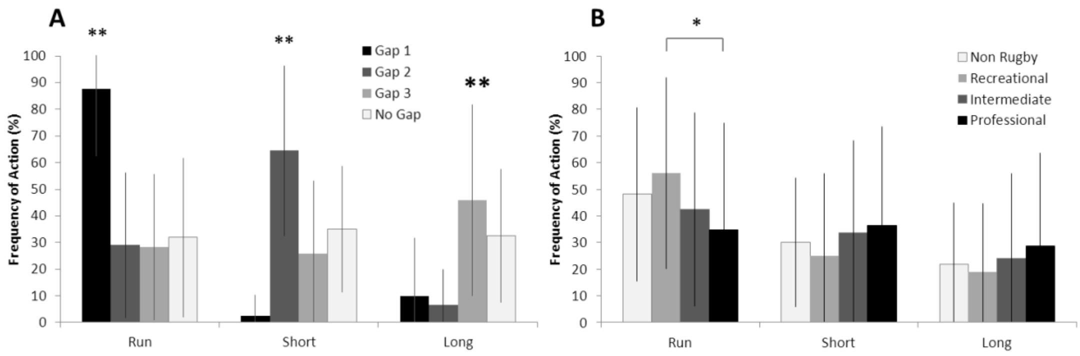

Figure 6.3. Panel A shows gap location broken down as a function of the three possible actions: run, short or long pass. Panel B shows how the distribution of action choices (run, short or long pass) varied between groups. * $p < .05$. ** $p < .001$

6.4.1.3. Gap and Expertise Interaction effects on the Action performed

A significant Gap x Group interaction was also found for the three actions performed (see Table 6.1). For Gap 1 (Figure 6.4A) the groups performed the running action at a similar frequency (all $p > .05$). However, for Gap 2 (Figure 6.4B) the frequency of short passes was significantly greater for the professional group than for the recreational ($p = .008$) and the non-rugby ($p < .001$) groups but not for the intermediate group. The non-rugby group differed significantly ($p < .001$) from all the other groups except for the recreational group. For the rugby players, the recreational and intermediate groups differed significantly ($p = .023$), but not the intermediate and professional groups ($p > .05$). For Gap 3 (Figure 6.4C) the frequency of long passes for the professional group was significantly greater than the recreational ($p = .001$), and the non-rugby ($p < .001$) groups but not for the intermediate group ($p > .05$). Although the non-rugby group differed significantly from the intermediate group ($p = .003$), no significant differences were found between the recreational and the non-rugby and intermediate groups ($p > .05$).

For the no-gap condition (Figure 6.4D) no particular action was obvious, and only the frequency of the running action differed significantly between groups. This action was performed less often by the professional group compared to the recreational (p = .070) or the non-rugby playing group (p = .027). For both short and long passes no significant differences were found between the groups (p > .05).

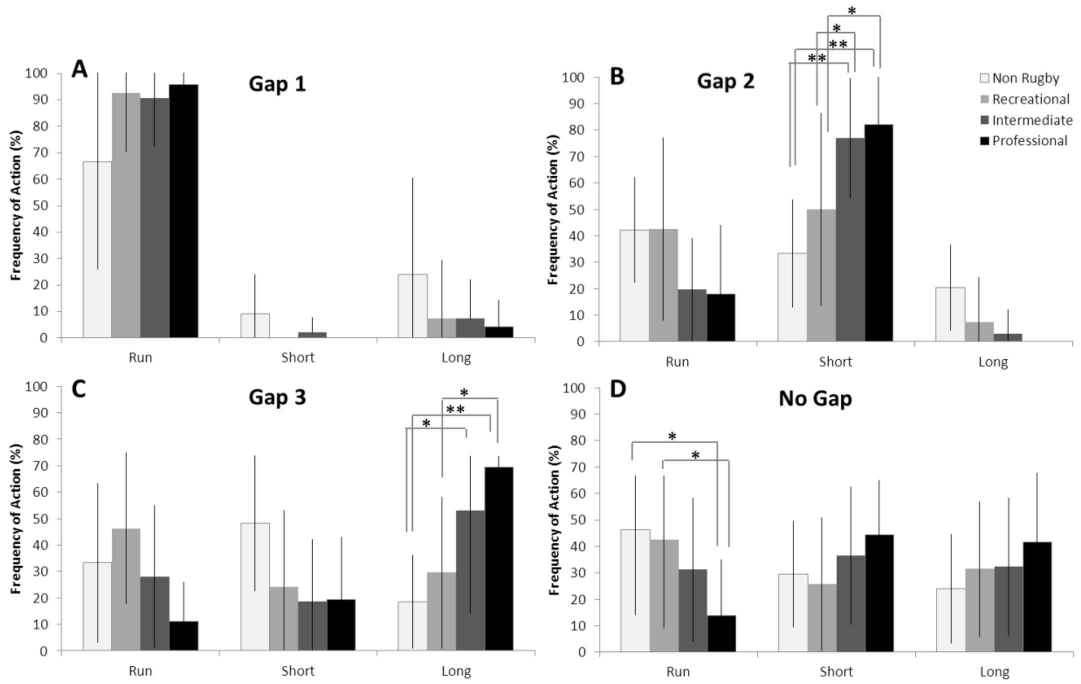

Figure 6.4. The two panels show each defensive gap location broken down as a function of the three possible actions. Panel A: Gap 1 corresponds to a gap opening in ball-carrier's own running channel; Panel B: Gap 2 corresponds to a gap opening in the first receiver's running channel; Panel C: Gap 3 corresponds to a gap opening in the second receiver's running channel; Panel D: No Gap corresponds to the condition where no gap opens. * p < .05. ** p < .001.

6.4.2. Task achievement

The analysis presented above verifies that the frequency of the expected action for the different gap conditions was significantly higher than all the other possible actions (cf. the pilot study and head coach testimony). However, to examine the effect of progressive rugby expertise in terms of task achievement we considered a particular expected action as the action afforded by the location of an opening gap (i.e., Gap 1 a running action, Gap 2 a short pass, Gap 3 a long pass) and looked at its frequency as a measure of task achievement. It is important to note that, as expected, in the No Gap condition no particular action possibility was deemed correct as the distance between defenders did not change during the course of the action. As this condition was simply a control condition it was not included in this analysis. A 4 (Group) x 3 (Gap) univariate ANOVA was thus conducted with task achievement as the dependent variable. Bonferroni post hoc tests were used to test for significant differences between conditions. Statistical significance was set at $p < .05$ level.

6.4.2.1. Gap effects on Task achievement

A gap main effect was found for task achievement ($F(2, 126) = 28.253$, $p < .001$, $\eta2_p = .310$). Achievement in Gap 1 ($M = 87.68$, $SD = 25.20$) was significantly greater than in Gap 2 ($M = 64.49$, $SD = 31.94$) and in Gap 3 ($M = 46.01$, $SD = 35.86$) ($p < .001$). Performance in Gap 2 was also significantly greater than Gap 3 ($p = .008$) (see Figure 6.5A).

6.4.2.2. Expertise effects on Task achievement

Was also observed a significant main effect of Group on task achievement ($F(3,126) = 14.964$, $p < .001$, $\eta2_p = .263$), with the non-rugby group ($M = 39.51$, $SD = 34.01$) performing significantly worse than the intermediate ($M = 73.61$, $SD = 31.67$) ($p < .001$) and the professional ($M = 82.41$, $SD = 25.18$) ($p < .001$) groups. Although lower than the recreational group ($M = 57.41$, $SD = 39.04$) the non-rugby group was not significantly lower ($p > .05$). Recreational group had though significantly lower performance than the professional group ($p = .003$). No significant differences were found between the recreational and the intermediate groups, or between the intermediate and the professional groups ($p > .05$) (see Figure 6.5B).

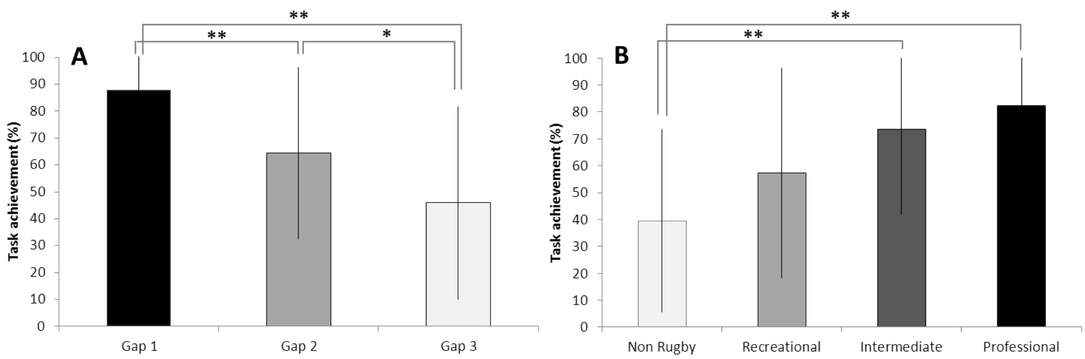

Figure 6.5. A: Gap location main effects. The percentages of task achievement (assumed as the frequency of the expected action) broken down as a function of the opening gap locations. Gap 1 corresponds to gaps opening in ball-carrier's own running channel; Gap 2 corresponds to

gaps opening in the first receiver's running channel; Gap 3 corresponds to gaps opening in the second receiver's running channel. B: Group main effects. Percentages of task achievement (assumed as the frequency of the expected action possibility) broken down as a function of each group of participants: non-rugby players, recreational, intermediate and professional rugby players.

6.4.2.3. Gap and Expertise Interaction effects on Task achievement

There was no significant Gap x Group interaction ($F(6, 126) = 1.11153$, $p = .336$, $\eta 2_p = .052$) on task achievement.

6.5. Discussion

In this study we examined how 'free' spaces (i.e., opening gaps) located in specific running channels influences the perception of action possibilities and ultimately the actions carried out. Furthermore, we investigated if this putative gap modulation of the players' actions might be related to differences between levels of rugby expertise. In order to accomplish this, we used an interactive 3vs3 VR rugby task.

6.5.2. Different Gap locations offer different actions independently of participants' expertise level

Depending on their locations, the manipulated defensive gaps shaped participants' behaviour. Overall when facing a gap opening in (i) their own running channel, (ii) in their first teammate's running channel, or (iii) in their second teammate's running channel, participants correspondingly often (a) ran (in their own channel), (b) passed short to their first teammate, or (c) passed long to their second teammate. The fact that non-rugby players and players alike perform a particular action suggests that the action most often selected for each gap location was the affordance that was best aligned with the task goals. Interestingly, for the no gap condition (where no gap was opening) no one particular action occurred significantly more often than any other. This may be considered as a demonstration of direct perception of action possibilities in the game of rugby union as recently pointed out by Craig and Watson (2011). According to these authors it is common to observe a player receiving the ball and requesting the teammates to perform a pre-planned move, such as to pass the ball wide. However, during the unfolding action it may be that an affordance is perceived, such as a gap opening in the nearest teammate's running channel, which creates a new opportunity for a short pass action, which overrides the pre-planned move.

Significant interactions were also found between gap location and expertise (i.e., group of participants) for the three actions performed. This distinction in the action carried out for the different gaps was more evident in the group of professional players. From an ecological perspective, perception-action coupling rests on the detection and use of information (Gibson, 1979). These performance variations, resulting from the experimental manipulation of gap location, suggest that information available in these manipulations is shaping the emerging actions (Beek, Dessing, Peper, & Bullock, 2003). None of the participants were especially familiar with the VR setting, so the differences observed here may be an indication of a greater functional fit between those participants who were already considered as "experts" in this rugby type situation. That is, professional players were better able to distinguish the information specifying the affordance in each of the varying gap conditions.

6.5.2. Rugby expertise effects in selecting the action for task achievement

In keeping with the above, the different manipulated defensive gap locations offer particular actions. The frequency of a given action was thus regarded as a measure of task achievement. For the overall groups of participants, achievement was best when the gaps opened in the participant's own running channel, not as good when in the first teammate's channel and least good in the case of the second teammate's running channel. These results suggest that it is easier to perceive an affordance for oneself than for others. The gaps emerging in different running channels also mean differences in terms of optical angles of each of those gaps from the viewpoint of the ball-carrier participant. Although in each location the size of the manipulated gap is equal, in terms of optical angles from the viewpoint of the ball-carrier they are very different (e.g., Gap 3 corresponds to the narrowest optical angle). Achievement differences or the difficulty to perceive the affordance for others - such as a gap opening further away through which a teammate could break the defensive line if the ball was passed to him – may be due to these differences in optical angles specifying the action afforded by those opening gaps. Besides, according to Smith and Pepping (2010) information specifying some affordances may be faster or easier to detect than others. This might also be the case of the present study. To further test this assumption, future research must address a description of these angles and how their change in space and time effects perception of affordance and achievement in this rugby sub-phase of the game.

For the overall gap conditions, rugby players were more successful than non-rugby players. Although they did not perform as well as the rugby players, non-rugby players still perceived similar gap affordances as rugby players. Within the groups of rugby players, the greater the experience of the players the greater the achievement in the task. This positive relationship between expertise and performance on this task suggests that the location characteristics of the dynamic opening gaps influenced the ball-carrier's decision-making behaviour.

These findings are consistent with the argument of expertise resting on the improved fit of the relationship between the performer and their environment (e.g., Araújo et al., 2009; Jacobs & Michaels, 2007; Turvey & Shaw, 1995). Given that the goal of the task was to break the defensive line whilst avoiding contact, performance of the professional group was more expert-like given its "contextualized functional value" (Araújo, 2007).

Starkes and Ericsson (2003) reported higher variability in athlete performance in expert-novice studies compared to observations of expert decision-making in actual performance context where they consistently shown high performances. This higher level of performance in situ was also shown in this experimental interactive and immersive VR rugby task. Moreover, expertise in sport is not often manifested solely in the ability to make perceptual judgements, but rather when perception is coupled to action (Craig et al., 2009; Farrow & Abernethy, 2003). Here, like in other studies (Craig et al., 2009; Dessing & Craig, 2010), we show expertise effects when perception and action are coupled.

Overall the findings convey the action fidelity characteristics of this task and outline how this technology has great potential to study decision-making in sport (Bideau et al., 2010). According to Stoffregen and colleagues (2003) this characteristic is demonstrated when there is a transfer from the simulator to the simulated system, i.e., to the actual performance context (Pinder, Davids, Renshaw, & Araújo, 2011). Decisional behaviour observed in participants in this experiment may be assumed as mirroring that of the actual sub-phase of the rugby game performance environment. Participants in this experiment acted only with respect to the information made available by dynamics of the movements of the defenders. If emergent action is like that expected in the real rugby situation, then this information is useful for the regulation of decisional behaviour in the actual performance context. One of this study's main advantages lies in the fact that experimentally controlled information that could not be normally controlled *in situ* can be controlled in the virtual environment, allowing for an in depth examination of how information shapes action. Moreover, it allow us to overcome some difficulties that are found *in situ* such as the impracticality of examining rugby-specific decision-making of non-rugby players given, for instance, the physical contact allowed in this game (Araújo et al., 2005).

In summary, this study sheds light on our understanding of decisional behaviour in a dynamic 3vs3 task where free spaces must be perceived as well as carrying out the appropriate action that allows performance goals to be achieved. By embracing perception-action coupling, whilst maintaining experimental control and manipulation over the information made available, this study demonstrates how even those without rugby experience can pick up the information specifying the opening of a gap and use it to shape their decision-making behaviour. Furthermore, by involving participants with different levels of expertise it was possible to demonstrate the effect of rugby expertise on perceiving and acting upon game relevant affordances.

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Chapter 7

General Discussion

7. General Discussion

The present thesis corresponds to a number of theoretical and empirical research articles aimed at replying to the following general questions related to decision-making in team sports: *how players' and teams' decision-making behaviour emerges and changes over time? what constrains it? and, what is the role of information in this process?* We believe we have accomplished such purpose and, like this, shed insights on the understanding of decision-making behaviour in team sports. Namely, focusing in the information constraints and the dynamics of interpersonal coordination in rugby union. In view of that, this final chapter serves primarily to make an overview of the main findings of the preceding chapters. Thenceforth some considerations are displayed concerning methodological issues from the empirical research undertaken along with theoretical and practical implications. As the most frequently asked question in the final stage of the PhD process was *what's next?* This last piece of the thesis embraces also some suggestions for further research.

7.1. Overview of main findings

In **Chapter 2** we provided a critical overview of research in decision making performance. We stressed how sport performance analysis and expertise in sport psychology programmes of research, both studying behaviour in sport, are largely centred on discrete actions by individual performers, or on discrete use of specific information sources, to describe successful performance. Accordingly, we argued how challenging for a superior understanding of decision-making and action in sport would be to direct instead research efforts to ongoing goal-directed interactions of performers. This, counting their context-dependency, alongside with assessing what information sources shape functional behaviours.

In **Chapter 3** we presented ball displacement data from rugby union matches demonstrating collective system dynamics of rugby second phases-of-play. Along these lines the emphasis was put on how teams interact over time and how this dynamics depicts system outcome. The variable "distance gained" revealed as a potential coordination variable defining the degree of territory gained by an attacking team and yielding the functional coordination between players and teams. Analysis of this variable showed the intermittent character of rugby union players' displacements and allowed prediction of the success or failure of second phases-of-play in this team ball sport. Based on our findings we purported that the distance gain dynamics portrays the collective behavioural pattern of multi-player attack-defence systems in team sports like rugby union.

For the empirical work depicted in **Chapter 4** we used also displacement data from rugby union matches. Yet this time data concerned trajectories of specific players involved at the beginning of the second phases-of-play to investigate whether time-to-gap-closure information was an underlying guiding mechanism of pass action. Results revealed that at the time-frame that the attacker receives the ball, the time-to-contact value predicted a great extent of the variance found in the characteristics of the subsequent pass. In addition, analysis of tau dynamics in two periods of the approach between the attacker and the defender, defined as the approach with and without the ball (i.e., before and after the attacker receives the ball), yielded two distinct patterned behaviours. Namely, a higher inter-trial variability and higher rate at which the gap is closing was observed during the approach ‘‘without the ball’’ but not in the approach ‘‘with the ball’’. The overall empirical observations presented in this chapter lead us to reason that this spatiotemporal variable may yield indeed information about future pass possibilities. Moreover, results suggested that task constraints acting on behaviour change throughout the game. For instance, the arrival on the scene (i.e., the interaction under analysis) of objects of the game such as the ball, together with the game particular rules (e.g., the allowed tackle), and opposing performance goals (e.g., to maintain vs to recover the ball) bring the coupling between players close to a potential physical contact circumstance. In this way, the changing informational fields constraining attacker–defender interaction may converge the channel of action possibilities towards a single pass solution.

In **Chapter 5** we presented empirical work demonstrating that task constraints such as defenders’ initial positioning in a 1 vs. 2 rugby union sub-phase shape players’ decision-making behaviours. Numerical advantage for the defending players may be expected to increase the likelihood of a successful tackle. In spite of this, the frequency of successful tries and successful tackles was verified to change with the manipulations carried out in the starting distance between defenders. Particularly, shorter starting distances between defenders, lower mean speeds of the three players, and a greater time period between the first crossover and the end of the trial were associated with a higher frequency of successful tackle outcomes. These findings were assumed as providing evidence of decision-making behaviour being differently expressed as a function of how far apart defenders are when initiating the task.

The data presented in **Chapter 6** highlighted how information in the context of performance shapes emergent decision-making behaviour. We stressed here the view of decision-making as the adaptive and functional process of perceiving and carrying out the affordances emergent in the context of performance (Araújo et al., 2006). By means of an interactive and immersive virtual reality set-up, we simulated a 3 vs. 3 rugby sub-phase that was performed by participants from the perspective of the ball-carrier. We manipulated the spaces between the defenders to form three differently located emergent gaps. The findings implied that spaces emerging between defending players were perceived and acted upon likewise by rugby and non rugby performers. That is, depending on gaps' location a particular action occurred more often as the action possibility (i.e., affordance) for all groups of participants. Additionally, results showed that the higher is expertise in rugby union the higher is achievement in this task.

7.2. Methodological considerations

The experimental studies reported in this thesis have embraced several methodological aspects pertaining to the participants, experimental setting, tools, and data analysis methods. However, of most importance is that the experimental task designs used were regarded as complying with the representative task design claimed by the Ecological Dynamics approach to decision making in sports (Araújo et al., 2006; Pinder et al., 2011). That is, all tasks demands were considered as matching characteristics of demands in the behavioural context to which the results are intended to be generalized. Using the actual match as the 'experimental' context the studies presented in chapters 3 and 4, though not allowing to exert control over variables (i.e., carry out experimental manipulation), had the advantage of allowing the systematic observation and analysis of behaviour on the match performance setting (Araújo et al., 2006). Study depicted in chapter 5 involved also a representative task undertaken in the same field where players would perform. In this study experimental manipulation was carried out by direct manipulation of contextual constraints that are relevant to this specific sport, such as: the number of players involved, the field boundary conditions and, specially, the initial position of players. In this way, it was possible to observe how task constraints influenced the dynamics of the emergent action. The empirical work reported in chapter 6 was accomplished by means of an immersive interactive virtual reality experimental set-up. Amongst other benefits, this technology allowed full control over the visual context of performance – namely over the information that was made available for the participants – and to simulate exactly the same task characteristics repeatedly (i.e., high reproducibility between trials), while upholding a representative task design.

7.3. Theoretical implications

Overall, the experiments and the ensuing results were discussed within the ecological dynamics of decision-making in sport (e.g., Araújo et al., 2006). Worth of note is that following this programme of research entails holding that information continuously constrains the behaviour patterned dynamics shaped between players while performing. Furthermore, it implies counting that players, within the dynamics of a match (e.g., 15vs.15 in rugby union) and its sub-phases (e.g., 1vs.2 or 3vs.3), come together in a goal-directed activity that, yielding coordination processes, underlies the configuration of the observed (inter)actions. Along these lines, the studies reported in this thesis may be considered has having given theoretical and empirical evidence and straightened out the importance of informational constraints and interpersonal coordination to decision-making behaviour in team sports, namely in the field invasion game of rugby union.

In the position paper (chapter 2) we stressed how research on decision-making performance is predominantly centred on the production of discrete actions by individual performers or on the (re)action on determinate informational stimulus. We discuss ecological dynamics as a potential theoretical framework to re-direct research to the ongoing interactions of performers and their environments, and the information that continuously guides players' goal-directed behaviours. Though we did undertook discrete action measures in the following empirical studies, we have emphasized the interactions (players-players-environment) rather than the decontextualized and isolated action of all of them. Furthermore, the shaping role of informational constraints on decision-making behaviour was also taken into consideration.

Previous studies on the dynamics of decision-making behaviours in team sports have been typically focused in 1vs.1 interactions (e.g., Araújo, Davids, Bennett, Button, & Chapman, 2004; Davids et al., 2006; Passos et al., 2008, 2009). The study reported in chapter 3 advanced in knowledge through the investigation of the interactions of many-to-many players in the team game of rugby union. Based on the results presented in that chapter we are confident in reporting that it is possible to identify in the actual game a variable that captures the collective actions of groups of players functioning as a social entity (i.e., team as a single entity or collective, cf. Bourbousson et al., 2010b; Kelso, 2009; Marsh, Richardson, Baron, & Schmidt, 2006) in terms of territorial conquest. Moreover, we have provided evidence that this variable's dynamics reveals features that may help to distinguish success of an attack during a second phase-of-play.

In chapter 4 we suggested that the direct perception of the time remaining until contact with the defender might inform the choice of pass (long or short) for the attacking rugby player. In the hypothesis and results discussed in this chapter, tau and its derivate variables were conceived as being relational invariants of a functional organism–environment interaction (Delafield-Butt & Schögler, 2007) and affordances highlighted as more than specific action possibilities, but rather as interaction or relational possibilities (Turvey, 1992). Findings suggested that instead of making complicated computations and inferences about kinematic measures of the approach (e.g., distance, velocity of approach), players may be simply picking up relevant information embedded in the dynamics of the performance context (i.e., from the dynamics of the gap closure as specified by tau). One of the advantages of the design of this study is that it allowed the investigation of informational parameters embedded in the unfolding interaction between the players and environment and its relation to action parameters that determine successful performance (e.g., effective passes) in the actual game.

In chapter 5 we have addressed evidence that task initial constraints (e.g., initial positioning) in a 1vs.2 rugby union performance situation influences players' decision-making behaviours. We demonstrated how team sport behaviour, instead of regarded as stereotyped and rigid, should be better understood as flexible and tailored in a goal-directed manner to current environmental conditions or task demands (Warren, 2006). This study's findings suggested that action paths developed by players yield a dynamic process guided by the changes in spatiotemporal information defined by the relative positioning between the performers (cf. e.g., Araújo et al., 2006; Warren, 2006; Warren & Fajen, 2004).

The study in chapter 6 comprised a lab experiment that used virtual reality equipment to manipulate the visual information available for the subject, namely the dynamics of the movements of the defenders, and examined how participants acted in a goal-directed way with respect to that information. This study gave us evidence on our understanding of decisional behaviour in a dynamic 3vs.3 task where free spaces must be perceived as well as carried out the action that allows performance goals to be achieved. By embracing perception-action coupling, whilst maintaining experimental control and manipulation over the information made available, this study shows evidence that even participants without rugby experience can pick up and act upon the information specifying action (i.e. to run, make a long pass, or a short pass) that unfolds the opening of a defensive gap,. Furthermore, it seems that to perceive the action afforded by an opening gap in the own running channel (i.e., run action) is easier than to perceive the same action afforded for others (i.e., run action performed by other) by a gap opening in their running channels (that would imply the option for a pass rather than keeping the ball). Interestingly also is that rugby level of expertise is suggested as influencing processes of detecting and acting upon game relevant affordances.

7.4. Future research

To empirically and unambiguously verify the existence of a collective, or a coordination variable, qualitative changes must be observed in this variable caused by variation in the control parameter (Kelso, 1995, 2009). Even though distance gained was presented as an impending coordination variable of second phases-of-play in rugby union (chapter 3), further work is needed to identify potential control parameters that may influence the behavioural transitions or qualitative changes in this variable. Besides, for further generalisation, this variable (or adaptations of it) should be tested in other sub-phases of game, and perhaps also target other team ball sports.

The line of work reported in chapter 4 should also be taken further into account. Specifically, further research is needed to deepen analysis of the surrounding dynamics of each situation (e.g., movement patterns of the players involved) and the inclusion of other potential informational variables. Such research must address not only the gap between first receiver and the nearest defender, but also consider the motion-gaps between other players (e.g., between the second receiver and the correspondent nearest defender, and between both defenders and both attackers) in order to investigate potential tau-couplings underlying the emergent coordination amongst players. In spite of this, to test whether pass action is actually regulated by tau, experimental manipulation of information is needed, while keeping with ongoing action coupled to perception. This could be achieved by means of virtual reality technology.

One implication of the results of chapter 6 was that it seems easier to perceive the action afforded for oneself than for others (i.e., to perceive the action afforded by an opening gap in our own running channel than in the running channel of others). As mentioned in that chapter, the different locations of the opening gaps imply also different optical angles from the viewpoint of the ball-carrier participant specifying the action afforded. It would be thus of particular interest that further studies include a formal description of these angles and investigate how their changes in space and time influence perception of affordance and achievement in this 3vs.3 sub-phase of the rugby game. Besides, future work could explore the relationship between individual and team’s performance in immersive and interactive virtual simulated sub-phases of game.

7.5. Practical implications

Overall, this thesis provided data that highlight the importance of promoting teaching and training sessions in which performers are offered the possibility of practicing under task constraints that bring about emergent functional behaviours representative of the performance context that is aimed.

One implication of these findings for practice in sports such as rugby union is that practice simulations can be more faithfully designed to intentionally control the way in which task constraints manipulations result in specific behaviours (e.g., Pinder et al., 2011). For instance, game-based training offer opportunities to practice territorial takeover, try-scoring or try-avoidance behaviours, but the identification and manipulation of key spatiotemporal variables (e.g., the different distances between, and speeds of, approaching players) can increase the frequency with which these specific functional behaviours emerge in practice and promote players' adaptations within critical performance regions. That is, coaches' options to manipulate specific constraints should include variability allowing players to seek unique performance solutions but simultaneously be aware about the adaptations that this kind of manipulations promotes in the players (Davids, Glazier, Araújo, & Bartlett, 2003).

The study carried out using immersive virtual reality (VR) set-up may be considered as sustaining the increasingly recognized potential of this methodology for practice purposes (Bideau, Kulpa, Vignais, Brault, Multon, & Craig, 2010). We showed that through VR we could simulate performance environments to explore players and non-players perception-action couplings while performing sub-phase of rugby game and analyse them in terms of goal achievement. In the same way, these sub-phase virtual simulations, and virtual simulations of other sub-phases of game, could be also used in off-field training (Bideau et al., 2010). For instance, knowing the constraints that in 'natural' contexts influence behaviour, a coach could use immersive and interactive virtual reality set-ups to simulate those constraints. Experiencing these simulations would allow the coach himself to better understand the unfolding dynamics shaping their players' behaviour and what may have influenced their action path selection in a functional or non-functional way in goal achievement terms. This could help coaches not only to make more accurate performance diagnostics, but also to better design training sessions potentiating a variation of similar situations in which players could enhance performance by attuning and calibrating the perception-action coupling underlying goal achievement (Araújo & Davids, 2011). Simultaneously, coach would be more able to call players' attention to some relevant information sources. For instance, the differences observed in ball-carrier's performance according to opening gap locations provided also evidence that training tasks should be designed that are representative of these gaps in terms of the specific areas of the field in which they appear (in relation to the ball-carrier's position). That is, training programs aimed to offer players practice in these situations, both *in situ* or through virtual simulations, to enhance perception of the action possibilities that better help accomplish the performance goals in competitive settings.

Besides these potential training practical applications, the portrayal of the game in terms of functional coordination variables, such as the distance gained, could be adopted in match analysis towards a more functional explanation of game, assuming goal-directed ongoing interaction between players rather than individual discrete and unrelated actions (Travassos, Araújo, Correia, & Esteves, 2010).

A better understanding of decision-making behaviour in team sports such as rugby union and namely the informational constraints and the dynamics of interactions between players in different game settings, may allow coaches to draw on more useful data to improve analysis, training and competition management.

7.6. Concluding Remark

With this thesis we believe that we provide a better understanding of the game, showing the influence of several variables in both interpersonal interaction and outcomes. Dynamics of ball movement, the spatiotemporal measure time-to-contact between opposing players, initial distance between defenders, and opening gaps location, shaped the emergent decision-making behaviour of the players in different scenarios and using different levels of manipulation. This was accomplished by means of representative match scenarios, and full manipulation of the performance environment through virtual reality set-up. These studies kept the perception-action couplings and the individual-environment relationship of the contexts towards which these findings are aimed to generalize. We ended by showing that the information available in the environment shapes participants behaviour independently of level of expertise in that specific team ball sports domain. Overall findings highlighted that the ever changing performance constraints in game, or game sub-phases, lead to adaptive changes in interpersonal coordination patterns that underlie decision-making.

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