ELSEVIER

VOLUME 15 ISSUE 3
MAY 2012

Journal of Science and
Medicine in Sport

SPORTS
MEDICINE
AUSTRALIA

Original research

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

Vanda Correia [a,*], Duarte Araújo [a], Ricardo Duarte [a], Bruno Travassos [a,b], Pedro Passos [a], Keith Davids [c]

[a] *Faculty of Human Kinetics, Technical University of Lisbon, Cruz Quebrada, Portugal*
[b] *University of Beira Interior, Covilhã, Portugal*
[c] *School of Human Movement Studies, Queensland University of Technology, Australia*

Abstract

Objectives: 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.

Design: 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.

Methods: 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.

Results: 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.

Conclusions: 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.

© 2011 Sports Medicine Australia. Published by Elsevier Ltd. All rights reserved.

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

1. 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.[4,5]

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

* Corresponding author.
E-mail addresses: advcorreia@fmh.utl.pt, correia.vanda@gmail.com (V. Correia).

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 leads 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 et al.[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,[11–13] 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.
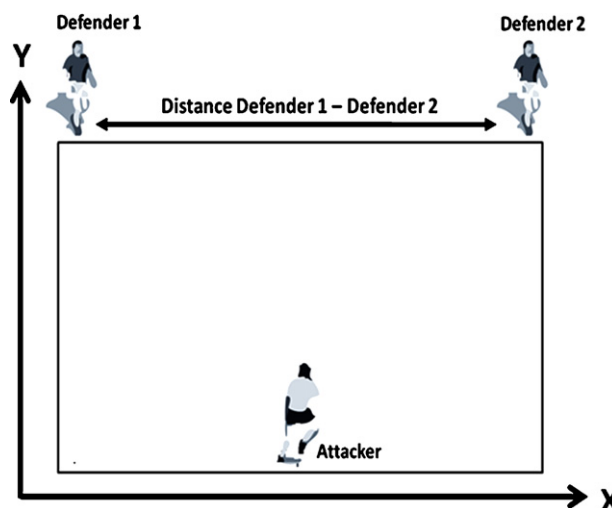

Fig. 1. A schematic representation of the 1 vs. 2 experimental task. The distance between Defender 1 and Defender 2 was manipulated in the experimental task.

2. Methods

Participants were 12, youth-level male rugby union players under 18 years of age (17.33 ± 0.49 years) with nearly 4 years competitive experience (3.91 ± 1.97 years). Participants provided voluntary and informed parental consent, the ethics committee of the Faculty of Human Kinetics (Lisbon, Portugal) approved this research with human participants, and all experimental procedures were conducted in compliance with the ethical guidelines proposed by the World Medical Association.[14] The representative experimental task[15] 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) × 10 m (depth) performance area. The try line corresponded to the line where the defenders were initially located (see Fig. 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.[16] 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: 3.55 ± 0.95 s).

Of the 12 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 20 1 vs. 2 trials (2 repetitions × 10 different defenders' starting distances). The entire experiment comprised a total of 80 1 vs. 2 trials.

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[17,18] that showed an accuracy higher than 95% using 25 images/s.[19] 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.[20] 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[20] and data were filtered using a Butterworth low-pass filter with a cut-off frequency of 6 Hz for all trials.[21] 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 to either 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
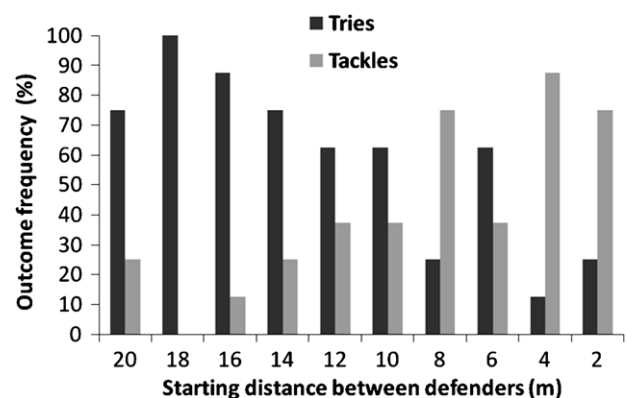

Fig. 2. Histogram of trial outcomes – try or tackle – over each value of the scaled starting distance between defenders. The bar values (vertical axis) indicate the percentage (%) of occurrence. The categories (horizontal axis) indicate the distance from which the defenders started the task in the corresponding sequence of change.

with the ball after an effective tackle by at least one of the defending participants).

Having ensured the data met the relevant parametric assumptions, 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.[22] Bonferroni's post hoc tests were used to identify the location of specific effects.

3. 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 Fig. 2). A higher frequency of try outcomes emerged at higher values of starting distance between defenders (i.e. 20–10 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 ($F (4, 28) = 3.87$, $p = 0.012$).
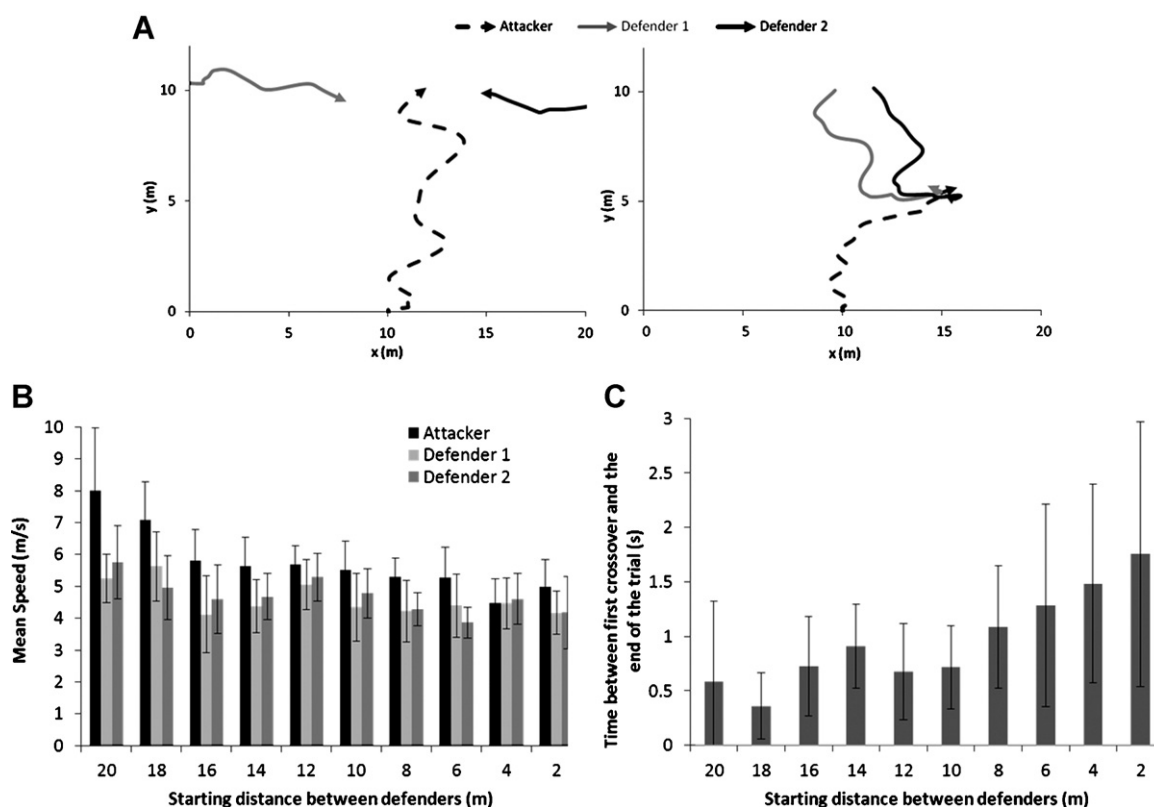
Fig. 3. (A) (upper panel): Exemplar trials of participants' movement displacement trajectories in the two extreme values of the manipulated starting distance between defenders. Left panel is a trial performed with the greatest value (i.e. 20 m) and in the right panel a trial performed with the smallest value (i.e. 2 m) of the manipulated distance. (B) (lower left 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 right 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.

Analysis of participants' movement displacement trajectories during each trial revealed changes in the displacement trajectories of defenders as a function of the manipulated starting distance (Fig. 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: $F_{(4, 30)} = 3.53$, $p \leq 0.001$). As Fig. 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 m) and 4 m (4.48 ± 0.72 m, $p \leq 0.02$) and 20 m and 2 m of the defenders' starting distances (4.99 ± 0.83 m, $p \leq 0.05$).

Follow-up tests also revealed significant decreases in the first defender's mean speed between 20 m (5.25 ± 0.73 m) and 8 m (4.22 ± 0.90 m, $p \leq 0.05$) of starting distances, and in the second defender's mean speed between 20 m (5.75 ± 1.09 m) and 6 m starting distances (3.86 ± 0.53 m, $p \leq 0.05$).

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 Fig. 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 Fig. 3A).

4. 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[23] 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 et al.[24] 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[24,25]). 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. Nonetheless, 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.[26] 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 starting distances between defenders which were first-order contextual constraints.[8,9] 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. 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.

6. 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 that emerge under constraints.

Acknowledgments

References

1. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. *Psych Sport Exerc* 2006;**7**:653–676.
2. Passos P, Araújo D, Davids K, et al. Information-governing dynamics of attacker–defender interactions in youth rugby union. *J Sport Sci* 2008;**26**:1421–1429.
3. Araújo D, Davids K, Cordovil R, et al. How does knowledge constrain sport performance? An ecological perspective, Chapter 10. In: Araújo D, Ripoll H, Raab M, editors. *Perspectives on cognition and action in sport*. New York: Nova Science Publishers; 2009.
4. Warren W. The dynamics of perception and action. *Psychol Rev* 2006;**113**:358–389.
5. Warren WH, Fajen BR. Behavioral dynamics of human locomotion. *Ecol Psychol* 2004;**16**(1):61–66.
6. Jacobs DM, Michaels CF. Direct learning. *Ecol Psychol* 2007;**19**(4):321–349.
7. Jacobs DM, Runeson S, Michaels CF. Learning to perceive the relative mass of colliding balls in globally and locally constrained task ecologies. *J Exp Psychol Human* 2001;**27**:1019–1038.
8. Juarrero A. *Dynamics in action: intentional behavior as a complex system*. Cambridge, MA: MIT Press; 1999.
9. Passos P, Araújo D, Davids K, et al. Power law distributions in pattern dynamics of attacker–defender dyads in the team sport of rugby union: phenomena in a region of self-organized criticality? *Emerg: Complex Org* 2009;**11**(2):37–45.
10. Van Orden GC, Holden JG, Turvey MT. Self-organization of cognitive performance. *J Exp Psychol Gen* 2003;**132**(3):331–350.
11. McGarry T, Anderson D, Wallace S, et al. Sport competition as a dynamical self-organizing system. *J Sport Sci* 2002;**15**:171–181.
12. Araújo D, Davids K, Bennett S, et al. Emergence of sport skills under constraints. In: Williams AM, Hodges NJ, editors. *Skill acquisition in sport: research, theory and practice*. London: Routledge; 2004 [Chapter 19].
13. Bourbousson J, Sève C, Mcgarry T. Space-time coordination dynamics in basketball: part 1. Intra- and inter-couplings among player dyads. *J Sport Sci* 2010;**28**(3):339–347.
14. World Medical Association. *Declaration of Helsinki – ethical principles for medical research involving human subjects*; 2008. Available at: http://www.wma.net/en/30publications/10policies/b3/index.html [accessed 14.12.09].
15. Araújo D, Davids K, Passos P. Ecological validity, representative design and correspondence between experimental task constraints and behavioural settings. *Ecol Psychol* 2007;**19**:69–78.
16. Southard D. Manipulating a control parameter in overhand throwing. In: Davis WE, Broadhead GD, editors. *Ecological task analysis and movement*. Champaign, IL: Human Kinetics; 2007. p. 97–114.
17. Fernandes O, Caixinha P, Malta P. Techno-tactics and running distance analysis by camera. *J Sports Sci Med* 2007;**6**(Suppl. 10):204.
18. Fernandes O, Folgado H, Duarte R, et al. Validation of the tool for applied and contextual time-series observation. *Int J Sport Psychol* 2010;**41**(4):63–64.
19. Fernandes O, Caixinha P. A new method in time-motion analysis in soccer training and competition. In: *5th world congress of science & football*. Lisboa: Ed. Gymnos; 2003. p. 270–271.
20. Duarte R, Araújo D, Fernandes O, et al. Capturing complex human behaviors in representative sports contexts with a single camera. *Medicina (Kaunas)* 2010;**46**(6):408–414.
21. Winter DA. *Biomechanics and motor control of human movement*. 3rd ed. New York: John Wiley & Sons; 2005.
22. Schutz R, Gessaroli M. The analysis of repeated measures designs involving multiple dependent variables. *Res Q Exercise Sport* 1987;**58**(2):132–149.
23. Kelso JAS. Coordination dynamics of learning and transfer across different effector systems. *J Exp Psychol Human* 2009;**28**(4):776–797.
24. Hristovski R, Davids K, Araújo D, et al. How boxers decide to punch a target: emergent behaviour in nonlinear dynamical movement systems. *J Sport Sci Med CSSI* 2006:60–73.
25. Kelso JAS. *Dynamic patterns. The self-organization of brain and behavior*. Cambridge, England: MIT Press; 1995.
26. Passos P, Milho J, Fonseca S, et al. Interpersonal distance regulates functional grouping tendencies of agents in team sports. *J Motor Behav* 2011;**43**(2):155–163.