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Shaping Tactical Behaviours in Football:

An Ecological Dynamics Approach

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Resumo

Na presente tese procura-se avançar com fundamentação teórica, demonstrações empíricas e orientações pedagógicas para a compreensão e modelação de comportamentos tácticos em equipas de futebol, aqui consideradas como sistemas adaptativos complexos. A fundamentação teórica proposta para explicar a emergência da coordenação funcional de equipa (considerada como comportamento tático) assenta na percepção de *affordances* coletivamente partilhadas, enquanto forma de ligação entre membros de equipa. Ao atuar guiados por *affordances* partilhadas, que emergem e dissipam-se sob a influência de constrangimentos, os jogadores formam sinergias cruciais para a redução dos graus de liberdade do sistema equipa, possibilitando a sincronização coletiva. Este processo foi capturado e analisado durante os movimentos rítmicos caraterísticos das equipas no jogo. Embora o número médio de sinergias emergentes não tenha revelado uma tendência crescente com o tempo de prática, verificou-se uma diminuição no tempo de reajustamento entre jogadores durante tais movimentos, resultante da criação dinâmica de informações que especificam *affordances* partilhadas. A importância da manipulação de constrangimentos na modelação de comportamentos táticos às escalas inter-individual, intra- e inter-equipa foi igualmente analisada em jogos reduzidos e condicionados (tarefas de treino comummente utilizadas para modelar comportamentos táticos). Ao manipular constrangimentos como dimensões do campo, relações numéricas e número de jogadores, é possível influenciar as interações jogador-jogador-ambiente. Tais manipulações resultaram em distintas distribuições espaciais e regiões dominantes individuais, forma, dispersão e posição relativa das equipas no campo, bem como em diferentes espaços criados entre atacantes e defesas. Estes dados traduzem a plasticidade dos comportamentos táticos resultantes da co-adaptação dos jogadores sob constrangimentos específicos. Em síntese esta tese permite revelar a importância da abordagem centrada nos constrangimentos no âmbito da modelação de comportamentos táticos em jogos coletivos como o futebol.

Palavras-chave: FUTEBOL, CONSTRANGIMENTOS, AFFORDANCES PARTILHADAS, SINERGIAS, JOGOS REDUZIDOS E CONDICIONADOS, COORDENAÇÃO INTER-PESSOAL, COMPORTAMENTOS TÁTICOS, GPS.

Abstract

This thesis aims to advance theoretical understanding, empirical evidence and pedagogical guidelines for shaping tactical behaviours in Football teams considered as complex adaptive systems.

A theoretical rationale was proposed to explain emergence of functional team coordination (here considered to depict tactical behaviours) in which perception of *shared affordances* (for self and for others) was considered to represent a communication network established between team members. By acting upon *shared affordances* that emerge and dissolve under changing constraints, team games players form interpersonal synergies, crucial for a reduction in system degrees of freedom, enhancing collective synchronization. This process was captured and analysed during the rhythmic ebb-and-flow movements of competing football teams. Although the average number of emergent synergies did not reveal an increasing trend with practice, there was a decrease in the readjustment delay of players' co-positioning as a result of the dynamic creation of informational properties, as *shared affordances* between performers. The role of constraints manipulation in shaping specific tactical behaviours at the inter-individual, intra- and inter-team levels was also analysed during small-sided and conditioned games (relevant practice tasks commonly used to shape tactical behaviours in football). By manipulating task constraints, like field dimensions, numerical relations and player numbers, practitioners can influence player-player-environment interactions. Such manipulations resulted in distinct emergent spatial distributions and dominant regions, team shapes, team dispersion and team relative positions on-field, as well as increasing or diminishing space separating attackers from defenders during performance. The data were interpreted as malleability of tactical behaviours resulting from distinct co-adaptations of players with teammates and opponents under specific task constraints. This research programme highlighted the value of a constraints-based approach for shaping tactical behaviours in team sports like football.

Keywords: FOOTBALL, CONSTRAINTS, SHARED AFFORDANCES, SYNERGIES, SMALL-SIDED AND CONDITIONED GAMES, INTERPERSONAL COORDINATION, TACTICAL BEHAVIOURS, GPS.

Chapter 1

General Introduction

1.1 Defining tactical behaviours

The term "tactics" has its origins in military activities and was first applied in the 17th century to refer to *"the art or science of disposing military or naval forces for battle and maneuvering them in battle[1]"*. This concept was further extended to the study of performance in team sports, since competitive matches, at one level, resemble a battle between two teams requiring functional and organized movements between its members. Therefore, the etymology of *tactic* refers to the *coordination* between members of a group looking to achieve specific performance goals. This understanding of the concept implies competing against and overcoming another group of individuals with the same objectives – a typical scenario of a competitive fixture where team members must *coordinate* actions in order to display functional levels of social organization.

In human movement systems, Bernstein (1967, p. 127) defined coordination as *"the process of mastering redundant degrees of freedom of the moving organ, in other words its conversion to a controllable system"*. The term degrees of freedom (dof) refers to the independent components of a system that could fit together in many different ways (Davids et al., 2008). The term 'redundant dof' was used by Bernstein to refer to the biomechanical dof that exceeded the minimum number required to successfully accomplish any given motor task (Davids et al., 2003). A solution to the problem relied on the formation of synergies, or coordinative structures (Kelso, 1998), to satisfy the constraints of a specific purpose or activity (e.g., kicking a ball). Synergies allowed the reduction of dimensionality by harnessing the control of dof that were specific to a particular task, while relinquishing control of nonessential system components (Beek et al., 2003), through the linkage of muscles and joints that lessen the dof requiring top-down control (Turvey, 1990).

Like neurobiological systems, football and other team ball sports can be considered complex adaptive systems composed of many interacting parts (players, ball, referees, pitch dimensions, etc.) (Davids et al., 2005; Glazier, 2010) affording the emergence of rich patterns of behaviour in dynamically

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[1] Source: Oxford Dictionaries (www.oxforddictionaries.com)

changing environments (Passos et al., 2008). Hence, interpersonal coordination between individuals (like players in team sports) can be framed in the same theoretical rationale (Marsh et al., 2009; Passos et al., 2009; Riley et al., 2012). The linkage of the dof of the motor system of two or more players into synergies can temporarily be assembled so that they can act as a single coherent unit (Kelso, 1998, 2012; Riley et al., 2011) at the level of *person-person-environment* interactions (Marsh et al., 2009). Thus, joint behaviours can translate to group behaviours as all players constrain and, in turn, are constrained by the dynamic, integrated system that they compose (Glazier, 2010).

Given the foregoing, for the purpose of this thesis, tactical behaviours are defined as the coordinated behaviours of three[2] or more players looking to cooperate and compete together to achieve common goals and communicating through synergetic relations (Araújo et al., 2015). Hence, tactical behaviours are the product of functional coordination achieved between interacting team members in space and time during performance.

1.2 Shaping tactical behaviours: Preview of the problem

Searching for new methods capable of producing a more pronounced training response has been one of the priorities of creative coaches (Issurin, 2008, 2013) that seek tirelessly to develop several performance-enhancing attributes in their players (Gabbett et al., 2009). Among these attributes, tactical skills are usually the most overemphasised, probably due to a general consensus that despite all factors being crucial for performance in competition, football matches are often won or lost on the basis of one team implementing a better tactical organization than an opposing team, especially at the elite performance level (Bartlett et al., 2012).

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[2] In social psychology two individuals form a dyad. Three is the minimum number for a group since it allows for simultaneous cooperation and competition among team members. With two, only one of these processes can occur (Hargie, 2011; Serpa, 1995).

Several studies have attempted to identify key tactical behaviours associated with successful competitive performance in team games (e.g., Adams et al., 2013; Bell-Walker et al., 2006; Castellano et al., 2012; Clemente, 2012; Grant et al., 1998; Grant et al., 1999; Hughes & Churchill, 2005; Low et al., 2002). Such studies support the view that understanding successful and/or unsuccessful tactical determinants during competitive fixtures may inform coaches about the most decisive factors for team and player development (Adams et al., 2013; Szwarc, 2007). Through this information, guidelines can be provided for the simulation of the tactical requirements of competitive soccer matches to facilitate further development of tactical factors within the appropriate context of a game during practice (see Fradua et al., 2013, for an example).

Analysis of training effects on individual and team performance have been usually guided by on-going monitoring, art and coaching experience (Taha & Thomas, 2003). In the absence of a sound theoretical support about the best training methods to improve tactical performance in team games, one concept that has emerged is the *"train as you play"* (Bishop, 2009). This approach advocates the use of team-sport-specific exercises delivered by the coach through a game-based training approach as a means of improving individual skill and physical fitness levels, simultaneously (Gabbett et al., 2009). However, there is little scientific evidence about the effects of this approach on enhancing learning of tactical behaviours.

A traditional approach to understanding the mastery of group processes that culminates in team effectiveness is predicated on the notion of group cognition. This concept is based on the premise that there exist shared mental models of the performance environment, internalised among all team members (Cannon-Bowers et al., 1993; Fiore & Salas, 2006; Salas et al., 2008). This representationist approach presupposes that players possess the necessary knowledge to evaluate the costs and benefits of every performance solution, without necessitating an interaction with the environment (Araújo et al., 2005; Davids & Araújo, 2010; Davids et al., 2007). Hence, decision making, perceptual judgements and actions would be dependent on knowledge structures stored in memory (Davids et al., 2007) and put into practice when activated by a specific stimulus (Passos et al., 2008). Shared cognition refers, therefore, to a state of group coordination in which each individual's specific mental expectation and representation of a performance context is similar or identical to that held by other team members (Eccles, 2010; Eccles & Tenenbaum, 2004).

Although shared cognition has tended to dominate research on coordination in groups, the mechanism to explain re-formulations of a team member's representation, when changes occur in the content of another member's representation, has proved difficult to verify (Mohammed, Klimoski, & Rentsch, 2000). Moreover, it is difficult to justify the existence of a brain that stores each player's representations (Shearer et al., 2009) and it is hard to consider that representations exist beyond the boundaries of an individual organism and can be somehow shared (Riley et al., 2011). Consequently, these questions highlight the lack of a convincing theoretical rationale available to explain team coordination, making it challenging to undertake an objective quantification and evaluation of tactical behaviours (Sampaio & Maçãs, 2012). Such limitations compromise the development of pedagogical principles to improve tactical skills and coaching practices.

1.3 An ecological dynamics account of tactical behaviour

There is a functionalist theoretical paradigm on movement coordination, grounded on prominent ideas of ecological psychology and nonlinear dynamics that emphasizes the study of movement behaviour as an emergent self-organizing property of the continuous interactions between a biological movement system and ecological constraints (Davids et al., 2007; Davids et al., 2006). The term "ecological dynamics" signifies an approach using concepts and tools of dynamical systems to understand phenomena that occur at an ecological scale – the scale where the relationship between individuals and their environments is defined (Araújo, 2013). This constraints-led perspective rejects any attempt to provide unilateral explanations of mind, body and environment.

Accordingly, the environment is perceived in terms of what the animal can do *with* and *within* the environment (Oudejans et al., 1996). This premise was pioneered by James Gibson (1966, 1979) who proposed the concept of *affordances* to refer to the invariants that humans perceive as possibilities for action. Performers perceive *affordances* according to each individual's movement system (e.g., limb length, strength, flexibility) (Fajen et al., 2009). Accordingly, objects also specify affordances, not individual neutral qualities or features. The object's affordances are the action possibilities that it provides to an individual with a given set of capabilities (e.g., an opportunity to shoot a ball at goal from a long distance is constrained by the performer's skill and limb power) (Vicente & Wang, 1998).

As the individual moves, new opportunities for action are provided while other are discarded or turned impossible, even though the surrounding context remains inalterable. Subtle changes of action can give rise to multiple variations in the opportunities for subsequent actions (Araújo, 2007). Thus, the control of individual tactical behaviours can be adjusted prospectively through the perception of these affordances that emerge within player-performance environment interactions (Araújo & Davids, 2011) by exploring and selecting relevant information that supports (tactical) decision-making during performance (Araújo et al., 2005; Oudejans et al., 1996). Therefore, cognitive processes expressed in tactical behaviours are understood and sustained on the environment-individual system and can be extended to group-environment relations (Marsh et al., 2006).

A team behavioural (tactical) landscape is thus continually shaped by the interaction of perceptions and intentions of players, as well as physical constraints, surrounding information and system dynamics (Davids et al., 2008) by pressurizing the selection of specific affordances. The phase space of the collective system is continuously defined by the surrounding constraints because they reduce the number of configurations available to that system. This constrained search for a solution is referred to as self-organizing optimality and emphasizes a more relativistic approach to human performance (Davids & Araújo, 2010).

1.3.1 Constraints on tactical behaviours with special reference to instructional constraints

So far, coordination (or, in the context of this thesis, tactical behaviour) has been considered to be a self-organized, synergetic process (Kelso, 1998, 2012) where states of collective system order emerge under constraints. When informational constraints of a task are altered, different patterns of movement coordination may emerge (Dicks et al., 2010; Pinder et al., 2009). This process opens new perspectives for shaping tactical behaviours in football teams.

Coordination, whether at the individual or multi-individual levels, is an emergent pattern-forming process shaped by the interaction among three categories of constraints (Newell, 1986) – environmental, organismic and task constraints. The interactions between the three classes of constraints acting on a system results in the emergence of different states of coordination that become optimized with practice and experience (Davids et al., 2008).

Environmental constraints are external to an individual refer to physical variables in nature such as ambient light, altitude, temperature, etc. Some environmental constraints are social rather than physical (social expectations, family support, etc.). They are usually the least accessible constraints on individuals for manipulation (Passos et al., 2008).

Organismic constraints refer to a person's characteristics such as genes, height, weight, skill, etc., and can be time independent (structural, e.g., weight, body shape, height, etc.) or time dependent (functional, e.g., synaptic connections) (Anson et al., 2005; Newell, 1986).

Task constraints are linked by the goal of the activity and are influenced by the goal, rules and/or other implements or machines or other individuals involved in an activity (Newell, 1986). They are more specific to performance contexts than environmental constraints and include task goals, specific rules, surfaces, performance areas, player-starting positions, number of players involved, etc. (Davids et al., 2008; Passos et al., 2008). Task-constraints manipulation is the most powerful tool available to coaches for improving the players' decisions and actions in a performance context (Passos et al., 2008), since their influence can override the effects of other relevant constraints

(Davids et al., 2007). Small-sided and conditioned games (SSCGs) constitute examples of task constraints manipulation that drive coordination towards desired outcomes. Despite its utility in this sense, there is still a lack of knowledge about how tactical behaviours emerge during SSCGs and how coordination patterns might emerge within specific SSGCs formats to be harnessed in shaping tactical performance.

Instructions are also considered relevant task constraints that can shape emergent decision-making processes (see Cordovil et al., 2009, for an example in 1 vs. 1 sub-phases of Basketball). In such contexts, affordances become intentional and are chosen for the purpose of satisfying an intention (Shaw, 2001). Different intentions are presumed to organize perceptual or perceptual-motor systems differently since they define what the perceiver intends to perceive (Jacobs & Michaels, 2007). If intentions change, the set of affordances relevant to a particular goal or combination of goals also changes (Kugler et al., 1990). Hence, instructions and tactics issued by the coach can be considered as task constraints (Glazier, 2010) and, through education and training of players, they can become organismic constraints in the form of experience (Davids et al., 2008). They drive each individual and the team, collectively, to perceive the relevant sources of information that allow them to harness intended self-organization processes, according to specific game phases and pre-set strategies.

Independently, sometimes too much emphasis is placed upon the coach's instructional constraints (usually, by coaches themselves). Verbal instructions can interfere with movement production because they add to the players' attentional load and interrupt their ability to satisfy task constraints (see Green & Flowers, 1991). From an ecological dynamics approach, what is advocated is that players, independently, discover and search for functional behaviours. It is also recommended that practitioners use verbal guidance, instructions and feedback only when the players cannot gain information about the task goal through their exploratory behaviours (Davids et al., 2008). Another limitation of instructional constraints is that, in critical regions of performance, typically characterised by low values of interpersonal distances between attackers and defenders, actions are not prescribed by coaches and the performance outcome can be precisely the one that players wanted to avoid, even when the coach instructed the players to avoid that outcome (Passos et al., 2013).

1.4 Structure and aims

Given the foregoing, the overall purpose of this thesis is to advance theoretical understanding and provide pedagogical guidelines for the effective acquisition and shaping of tactical behaviours in football. To this effect an explanatory model of team coordination in team sports is proposed, framed by an ecological dynamics rationale. The impact of practice and manipulation of task constraints (through SSCGs) on interpersonal coordination is adopted as a task vehicle for validating the proposed model. As a secondary goal, the influence of skill level (considered as an organismic constraint) on emergence of tactical behaviours is also considered.

This thesis encompasses a collection of six original research articles published in peer-review journals. All data were collected as kinematic time series of players' continuous movements during performance acquired via global positioning systems devices (GPS).

Chapter II (*"Shared knowledge or shared affordances: Insights from an ecological dynamics approach to team coordination in sports"*) presents a position statement in which traditional models of team cognition are challenged by an ecological dynamics approach to explain how team synergies (or coordinative structures), crucial for team coordination, are supported by the perception of informational constraints specified as shared affordances (i.e., affordances for self and others' affordances).

In chapter III (*"Practice effects on emergent intra-team synergies in football"*) the aim was to capture the emergent number of synergies established during match play and their synchronization speed as a result of the dynamic creation of shared affordances between players along with any effects of practice associated with team performance indicators. More precisely, the coupling tendencies of players were recorded, along with the players' movement readjustment delays during collective team movements.

Chapters IV and V verified the influence of field dimension and skill on emergent tactical behaviours during performance in SSCGs. Particularly, chapter IV (*"Effects of pitch size and skill level on tactical behaviours of Association Football players during small-sided and conditioned games"*) analysed movement variability of players on-field by assessing the uncertainty of the players' positioning with respect to spatial-temporal variables reporting the spatial distribution of players on field and the time-evolving nature of their movements around a positional spatial reference. In chapter V (*"Field dimension and skill level constrain team tactical behaviours in small-sided games"*) analyses of the effects of different field dimensions on tactical behaviour were extended to the intra- and inter-team levels, by assessing the teams' dispersion, their shapes and the spatial-temporal relations established between players and their nearest opponents.

In chapter VI (*"Numerical relations and skill level constrain co-adaptive behaviours of agents in sports teams"*) a neurobiological systems orientation was adopted to scrutinise the effects of skill level and manipulations of numerical relations on inter-individual, intra- and inter-team coordination processes. These analyses provided understanding about the changes undertaken by players of different competitive standards on their division of labour, teams' dispersion and relative position on field along with the interpersonal distance values established between opponents in specific sub-grouping alignments.

Chapter VII (*"Effects of manipulations of player numbers vs. field dimensions on inter-individual coordination during small-sided games in youth football"*) compared the effects of manipulations of field dimensions and of player numbers, replicating the same relative space per player during performance in SSCGs, on the emergence of surrounding informational resources near the vicinity of each player and their spatial distribution.

Finally, chapter VIII provides an overview of the main findings that were further discussed in line with the ecological dynamics framework. Theoretical and practical considerations were endorsed for shaping tactical behaviours in football and some suggestions for future research were presented.

1.5 References

Adams, D., Morgans, R., Sacramento, J., Morgan, S., & Williams, M. (2013). Successful short passing frequency of defenders differentiates between top and bottom four English Premier League teams. *International Journal of Performance Analysis in Sport, 13*, 653-668.

Anson, G., Elliott, D., & Davids, K. (2005). Information processing and constraints-based views of skill acquisition: divergent or complementary? *Motor Control, 9*(3), 217-241.

Araújo, D. (2007). Promoting ecologies where performers exhibit expert interactions. *International Journal of Sport Psychology, 38*, 73-77.

Araújo, D. (2013). *The ecological dynamics of tactical behavior in sport - Sinthesis lesson presented for the habilitation defense in the domain of Human Kinetics and the speciality of sport training*. Cruz Quebrada: FMH. Relatorio de Estagio apresentado a

Araújo, D., & Davids, K. (2011). Talent development: from possessing gifts, to functional environmental interactions. *Talent Development & Excellence, 3*(1), 23-25.

Araújo, D., Davids, K., & Serpa, S. (2005). An ecological approach to expertise effects in decision making in a simulated sailing regatta. *Psychology of Sport and Exercise, 6*, 671-692.

Araújo, D., Silva, P., & Davids, K. (2015). Capturing group tactical behaviors in expert team players. In J. Baker & D. Farrow (Eds.), *Routledge Handbook of Sport Expertise* (pp. 209-220): Routledge.

Bartlett, R., Button, C., Robbins, M., Dutt-Mazumder, A., & Kennedy, G. (2012). Analysing team coordination patterns from player movement trajectories in soccer: Methodological considerations. *International Journal of Performance Analysis in Sport, 12*, 398-424.

Beek, P., Jacobs, D., Daffertshofer, A., & Huys, R. (2003). Expert performance in sport: Views from the joint perspectives of echological psychology and dynamical systems theory. In J. Starkes & K. A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 321-344). Champaign, IL: Human kinetics.

Bell-Walker, J., McRobert, A., Ford, P., & Williams, M. (2006). A Quantitative Analysis of Successful Teams at the 2006 World Cup Finals. *Insight. The F. A. Coaches Association Journal, Autumn/Winter*, 37-43.

Bernstein, N. (1967). *The coordination and regulation of movements*. Oxford: Pergamon Press.

Bishop, D. (2009). Game sense or game nonsense? *Journal of science and medicine in sport / Sports Medicine Australia, 12*(4), 426-427.

Cannon-Bowers, J. A., Salas, E., & Converse, S. (1993). Shared mental models in expert team decision making. In J. J. Castellan (Ed.), *Individual and group decision makig*. Hillsdale, New Jersey: Erlbaum.

Castellano, J., Casamichana, D., & Lago, C. (2012). The use of match statistics that discriminate between successful and unsuccessful soccer teams. *Journal of Human Kinetics, 31*, 139-147.

Clemente, F. (2012). Study of successful soccer teams on FIFA World Cup 2010. *Pamukkale Journal of Sport Sciences, 3*(3), 90-103.

Cordovil, R., Araújo, D., Davids, K., Gouveia, L., Barreiros, J., Fernandes, O., & Serpa, S. (2009). The influence of instructions and body-scaling as constraints on decision-making processes in team-sports. *European Journal of Sport Science, 9*(3), 169-179.

Davids, K., & Araújo, D. (2010). The concept of "Organismic Asymmetry" in sport science. *Journal of Science and Medicine in Sport, 13*, 633-640.

Davids, K., Araújo, D., Button, C., & Renshaw, I. (2007). Degenerate brains, indeterminate behavior, and representative tasks: implications for experimental design in sport psychology research. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of Sport Psychology* (3rd ed., pp. 224-244). New Jersey: John Wiley & Sons, Inc.

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of dynamical system theory to Football. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science & Football V* (pp. 556-569). Oxon: Routledge.

Davids, K., Button, C., Araújo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human movement studies. *Adaptive Behavior, 14*, 73-94.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: a constraints-led approach.* Champaign (IL): Human kinetics.

Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: the functional role of variability and its implications for Sports Medicine. *Sports Medicine, 33*(4), 245-260.

Dicks, M., Button, C., & Davids, K. (2010). Examination of gaze behaviors under in situ and video simulation task constraints reveals differences in information pickup for perception and action. *Attention, Perception, & Psychophysics, 72*(3), 706-720.

Eccles, D. (2010). The coordination of labour in sports teams. *International Review of Sport and Exercise Psychology, 3*(2), 154-170.

Eccles, D., & Tenenbaum, G. (2004). Why an expert team is more than a team of experts: A social-cognitive conceptualization of team coordination and communication in sport. *Journal of Sport & Exercise Psychology, 26*, 542-560.

Fajen, B., Riley, M., & Turvey, M. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*, 79-107.

Fiore, S., & Salas, E. (2006). Team cognition and expert teams: developing insights from cross-disciplinary analysis of exceptional teams. *International Journal of Sport and Exercise Psychology, 4*(4), 369-375.

Fradua, L., Zubillaga, A., Caro, Ó., Iván Fernández-García, Á., Ruiz-Ruiz, C., & Tenga, A. (2013). Designing small-sided games for training tactical aspects in soccer: Extrapolating pitch sizes from full-size professional matches. *Journal of Sports Sciences, 31*(6), 573-581.

Gabbett, T., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching, 4*(2), 273-283.

Gibson, J. (1966). *The senses considered as perceptual systems*. Boston: MA: Houghton Mifflin.

Gibson, J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Glazier, P. S. (2010). Game, set and match? Substantive issues and future directions in performance analysis. *Sports Medicine, 40*(8), 625-634.

Grant, A., Williams, A., & Borrie, A. (1998). Analysis of the successful and unsuccessful teams in the 1998 World Cup. *Insight. The F. A. Coaches Association Journal, 2*(1), 1-4.

Grant, A., Williams, A., & Reilly, T. (1999). An analysis of the successful and unsuccessful teams. *Journal of Sports Sciences, 17*(10), 827.

Green, T., & Flowers, J. (1991). Implicit versus explicit learning processes in a probabilistic, continuous fine-motor catching task. *Journal of Motor Behavior, 24*(3), 290-300.

Hargie, O. (2011). *Skilled Interpersonal Interaction: Research, Theory, and Practice* (5th ed.). London: Routledge.

Hughes, M., & Churchill, S. (2005). *Attacking profiles of successful and unsuccessful teams in Copa America 2001*. London: Routledge. Relatorio de Estagio apresentado a

Issurin, V. (2008). *Block periodization 2: fundamental concepts and training design.* Muskegon: Ultimate Training Concepts.

Issurin, V. (2013). Training transfer: Scientific background and insights for practical application. *Sports Medicine, 43*, 675-694.

Jacobs, D., & Michaels, C. (2007). Direct learning. *Ecological Psychology, 19*(4), 321-349.

Kelso, J. A. S. (1998). From Bernstein's physiology of activity to coordination dynamics. In M. Latash (Ed.), *Progress in motor control. Bernstein's traditions in movement studies* (pp. 203-219). Champaign, IL: Human Kinetics.

Kelso, J. A. S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 367*, 906-918.

Kugler, P., Shaw, R., Vicente, K., & Kinsella-Shaw, J. (1990). Inquiry into intentional systems I: Issues in ecological physics. *Psychological Research, 52*, 98-121.

Low, D., Taylor, S., & Williams, A. (2002). A quantitative analysis of successful and unsuccessful teams. *Insight. The F. A. Coaches Association Journal, 4*, 86-88.

Marsh, K., Richardson, M., & Schmidt, R. (2009). Social connection through joint action and interpersonal coordination. *Topics in Cognitive Science, 1*, 320-339.

Marsh, K., Richardson, M. J., & Baron, R. M. (2006). Contrasting approaches to perceiving and acting with others. *Ecological Psychology, 18*(1), 1-38.

Newell, K. (1986). Constraints on the development of coordination. In M. G. Wade & H. T. A. Whiting (Eds.), *Motor development in children: Aspects of coordination and control* (pp. 341-360). Dorddrecht: Martinus Nijhoff.

Oudejans, R., Michaels, C., Bakker, F., & Dolné, M. (1996). The relevance of action in perceiving affordances: perception of catchableness of fly balls. *Journal of Experimental Psychology: Human Perception and Performance, 22*(4), 879-891.

Passos, P., Araújo, D., & Davids, K. (2013). Self-Organization Processes in Field-Invasion Team Sports. *Sports Medicine, 43*(1), 1-7.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Serpa, S., & Milho, J. (2009). Interpersonal pattern dynamics and adaptative behavior in multiagent neurobiological systems: conceptual model and data *Journal of Motor Behavior, 41*(5), 445-459.

Passos, P., Araújo, D., Davids, K., & Shuttleworth, R. (2008). Manipulating constraints to train decision making in Rugby Union. *International Journal of Sports Science & Coaching, 3*(1), 125-140.

Pinder, R., Renshaw, I., & Davids, K. (2009). Information-movement coupling in developing cricketers under changing ecological practice constraints. *Human Movement Science, 28*(4), 468-479.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Riley, M., Shockley, K., & Orden, G. V. (2012). Learning from the body about the mind. *Topics in Cognitive Science, 4*, 21-34.

Salas, E., Cooke, N. J., & Rosen, M. A. (2008). On teams, teamwork, and team performance: discoveries and developments. *Human Factors, 50*(3), 540-547.

Sampaio, J., & Maçãs, V. (2012). Measuring tactical behaviour in football. *International Journal of Sports Medicine, 33*(5), 395-401.

Serpa, S. (1995). La rélation coach-athlète: principaux courants de la recherche en Europe. *Sport, 151*, 6-17.

Shaw, R. (2001). Processes, Acts, and Experiences: Three Stances on the Problem of Intentionality. *Ecological Psychology, 13*(4), 275-314.

Shearer, D. A., Holmes, P., & Mellalieu, S. D. (2009). Collective efficacy in sport: the future from a social neuroscience perspective. *International Review of Sport and Exercise Psychology, 2*(1), 38-53.

Szwarc, A. (2007). Efficacy of successful and unsuccessful soccer teams taking part in finals of Champions League. *Research Yearbook, 13*(2), 221-225.

Taha, T., & Thomas, S. (2003). Systems modelling of the relationship between training and performance. *Sports Medicine, 33*(14), 1061-1073.

Turvey, M. (1990). Coordination. *American Psychologist, 45*(8), 938-953.

Vicente, K., & Wang, J. (1998). An ecological theory of expertise effects in memory recall. *Psychological Review, 105*(1), 33-57.

Chapter 2

Shared Knowledge or Shared Affordances? Insights From an Ecological Dynamics Approach to Team Coordination in Sports [3]

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Abstract

Previous research has proposed that team coordination is based on shared knowledge of the performance context, responsible for linking teammates' mental representations for collective, internalized action solutions. However, this representational approach raises many questions including: how do individual schemata of team members become reformulated together? How much time does it take for this collective cognitive process to occur? How do different cues perceived by different individuals sustain a general shared mental representation? This representational approach is challenged by an ecological dynamics perspective of shared knowledge in team coordination. We argue that the traditional shared knowledge assumption is predicated on *"knowledge about"* the environment, which can be used to share knowledge and influence intentions of others *prior to* competition. Rather, during competitive performance, the control of action by perceiving surrounding informational constraints is expressed in *"knowledge of"* the environment. This crucial distinction emphasizes perception of shared affordances (*for* others and *of* others) as the main communication channel between team members during team coordination tasks. From this perspective, the emergence of coordinated behaviours in sports teams is based on the formation of interpersonal synergies between players resulting from collective actions predicated on shared affordances.

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[3] Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*, 765-772.

2.1 Introduction

In everyday life, individuals coordinate movements with behaviours of others in order to achieve simple task goals like walking and talking to friends

(Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007). The ability to coordinate actions with those of others is often paramount for succeeding in specific performance contexts (Sebanz, Bekkering, & Knoblich, 2006), such as competitive team sports.

A traditional approach to understanding team coordination in sports involves the idea of group cognition grounded on the premise of shared knowledge of the performance environment internalised among all team members (Fiore & Salas, 2006; Salas, Cooke, & Rosen, 2008). These ideas are rooted in a key principle of cognitive science that performance (whether individual or collective) is predicated on the existence of a representation or schema, responsible for the organization and regulation of behaviours (Rentch & Davenport, 2006; Schmidt, 1975). Alternatively, an ecological dynamics perspective of team coordination focuses on the available informational constraints that afford possibilities for controlling goal-directed activity in individuals, often with others (Araújo, Davids, & Hristovski, 2006; Vilar, Araújo, Davids, & Button, 2012). This theoretical paradigm has underpinned several recent studies investigating interpersonal coordination tendencies of sub-groups and teams in several sports (Correia, Araújo, Davids, Fernandes, & Fonseca, 2011; Folgado, Lemmink, Frencken, & Sampaio, 2012; Frencken, De Poel, Visscher, & Lemmink, 2012; Travassos, Araújo, Duarte, & McGarry, 2012).

Despite relying on different premises, both theories have been used arbitrarily to evaluate coordination during team performance. For example, Bourbousson and colleagues used both dynamical systems and social-cognitive conceptual approaches to study coordination tendencies in Basketball teams (Bourbousson, Poizat, Saury, & Seve, 2010; Bourbousson, Poizat, Saury, & Seve, 2011; Bourbousson, Sève, & McGarry, 2010b).

Here, we challenge the concepts of shared knowledge and team cognition and propose that team coordination is, rather, predicated on shared affordances, substantiated by theoretical ideas of ecological dynamics.

2.2 Team cognition models and the concept of shared knowledge

Group functioning involving multiple cooperating individuals has traditionally been conceptualised to be based on social and cognitive processes (Eccles, 2010), suggesting that understanding skilled team performance in sport could be developed by studying internalised processes of cognition in collective systems (Ward & Eccles, 2006). This idea has been predicated on the assumption of shared knowledge between individuals in collectives, viewed as crucial for successful team performance (Reimer, Park, & Hinsz, 2006; Salas, Rosen, Burke, Nicholson, & Howse, 2007). The concept of shared knowledge has been addressed in cognitive, social and organisational psychology (Eccles, 2010), and a key aim has been to understand how shared knowledge can be represented in groups of coordinating individuals. Its central assumption hypothesizes that individuals belonging to the same group or team maintain some kind of representation of shared knowledge or understanding in common (Cooke, Salas, Kiekel, & Bell, 2004; Eccles & Groth, 2006; Fiore & Salas, 2006; Salas, et al., 2008; Salas, et al., 2007; Ward & Eccles, 2006). It is typically referred to as a state of group coordination in which each individual's specific representation of a performance context is similar or identical to that held by team members (Eccles, 2010; Eccles & Groth, 2006). The assumption of shared knowledge results from the possession by team members of complementary goals, strategies and relevant tactics, providing a basic shared understanding of desired performance outcomes. Shared knowledge underpins how each team member, individually, and the team globally, aims to achieve performance goals (Eccles & Groth, 2006; Ward & Eccles, 2006). Team members form clear expectations about each other's actions, allowing them to coordinate quickly and efficiently in adapting to the dynamic changes and demands of competitive performance environments, like sport, by selecting appropriate goal-directed actions to execute at appropriate times (Eccles, 2010; Eccles & Tenenbaum, 2004; Reimer, et al., 2006; Salas, et al., 2007). In this context, the processing of information is considered to play a crucial role in understanding how shared cognitive entities putatively provide the basis of players' decision making in team sports (Reimer, et al., 2006).

Previous reviews addressing social cognition models have emphasized shared knowledge believed to be associated with team effectiveness (Kozlowski & Ilgen, 2006; Mohammed & Dumville, 2001) and collective efficacy (Shearer, Holmes, & Mellalieu, 2009) by proposing, for example, that "the more teammates have a shared understanding of their situation, the more cohesive the team will be" (Reimer, et al., 2006), with higher levels of cohesion signifying higher degrees of coordination. In this case, team efficacy may increase when a sophisticated, global and comprehensive representation of a collective action is linked to a mental representation of a performance context, somehow shared by all players and put into practice. An asynchrony between the goals of individual performers and those of the team imply that a shared state has yet to be achieved, with resulting difficulties in coordination between players (Eccles, 2010).

The role of explicit memorised knowledge is emphasized in each individual player for successful team functioning. Practice and experience are deemed important for enhanced encoding of domain-specific information in, and retrieval, from long-term memory structures (Eccles & Tenenbaum, 2004). They are also relevant for the formation of new and more elaborated representations or schemas, developed by performers for regulating behaviours in task-specific situations (Eccles, 2010; Eccles & Tenenbaum, 2004; Ward & Eccles, 2006). The shared awareness of "who knows what" is seen as complementing the knowledge possessed by each individual player and is considered to form a transactive memory network responsible for underpinning each team member's awareness of that unique performance knowledge (Eccles & Groth, 2006; Kozlowski & Ilgen, 2006; Mohammed & Dumville, 2001).

Several studies have attempted to understand how team members exchange and share knowledge during performance, assuming that this accounts for team coordination in competitive sport events like doubles in tennis (Tenenbaum, Lausic, & Eccles, 2005), table tennis (Blickensderfer, Reynolds, Salas, & Cannon-Bowers, 2010; Lausic, Tennebaum, Eccles, Jeong, & Johnson, 2009; Germain Poizat, Bourbousson, Saury, & Seve, 2012; G. Poizat, Bourbousson, Saury, & Sève, 2009), as well as in basketball (Bourbousson, Poizat, et al., 2010; Bourbousson, Poizat, Saury, & Seve, 2012). These studies have mainly used videotaped and audiotaped matches and/or verbal reports and questionnaires during post-match interviews as methods for coding and categorizing communication exchanges between teammates. Using such methods, Bourbousson, Poizat, et al. (2010) reconstructed the courses of action of each of five players in a basketball team and then synchronized them. They found that players were only able to verbalize about all their teammates' behaviours when they were outside the match while they focused on only one or two teammates to coordinate their actions during the match. It was concluded that basketball players coordinate their actions by making local adjustments and enhancing their interactions with a single teammate, and not by grasping the full game situation.

2.2.1 Challenges for team cognition models

Criticisms and questions about models of team cognition, and the key concept of shared knowledge, have emerged from within the field itself. Although shared knowledge has tended to dominate research on mental models in collective systems, and is still accepted as a necessary pre-condition for the emergence of team coordination, some investigators claim that it needs to be conceptually reformulated and much more carefully defined (Kozlowski & Ilgen, 2006; Shearer, et al., 2009; Ward & Eccles, 2006). It is argued that players possess different types of knowledge (Mohammed, Klimoski, & Rentsch, 2000) (e.g., declarative, procedural and strategic knowledge) (Mohammed & Dumville, 2001) that account for different knowledge of the game (e.g., knowing 'how' to do and knowing 'what' to do). Further, perceptual cues are likely to be used differently by each individual, according to their skill level, type of practice engaged in or simply due to the relatively distinct contribution of each team member to each phase of play (Ward & Eccles, 2006). Thus, knowing "who knows what" at each moment of a match would involve a tremendous cognitive load.

Particularly, the mechanism to explain re-formulations of a team member's schema, when changes occur in the content of another member's schema, has proved difficult to verify (Mohammed, et al., 2000). In some cases, decision-making in sports might seem to depend upon the execution of a plan and a contingency in which shared knowledge of plans might be useful (Ward & Eccles, 2006). Consider, for example, Association Football, when some players combine in advance the way they are going to execute a set piece such as a free-kick. Yet, during the set piece itself, a predefined decision might become infeasible due to last minute constraints imposed by the actions of opposing team players. The mechanism through which a group of expert players adapts to the new conditions within seconds is still to be demonstrated by team cognition models. Several studies have failed to find significant relationships between measures of convergence of mental models and various dimensions of team performance (Mohammed & Dumville, 2001). From a biological point of view, the existence of a brain that stores each player's representations is utopian (Shearer, et al., 2009) and it is hard to consider that representations exist beyond the boundaries of an individual organism and can be somehow shared (Riley, Richardson, Shockley, & Ramenzoni, 2011).

Social cognitive models are grounded on rational models of decision-making, which assume that athletes possess the necessary knowledge to mentally evaluate the costs and benefits of every specific performance solution. By admitting the existence of an equally accessible inference for every person, that differentiates between correct and incorrect decisions (regarding a specific performance goal in a given context), there is no room for response variability (Davids, Araújo, Button, & Renshaw, 2007). This is because rationality is only viable in closed systems (e.g., computers) where specific outcomes are triggered through linear processes, ignoring the constraints continuously imposed on performers (Araújo, Davids, & Serpa, 2005; Davids & Araújo, 2010; Davids, et al., 2007).

Ferrario, Sforza, Dugnani, Michielon, and Mauro (1999) provided evidence of inter-trial variability in a team coordination task that challenges this view. They analysed the within-team positional variability of semi-professionals and amateur football players while performing two pre-planned and rehearsed offensive patterns of play. The coefficients of variation found in the relative players' positioning across trials highlighted the implicit variability characterizing every performance task and the impossibility to re-create, a priori, the exact movement actions in a rehearsed task.

There are other important questions to be considered. Is there enough time for the processing of a significant amount of information between individual members of a team during performance (15 v 15 in Rugby Union and 18 v 18 in Australian Rules Football)? In most sports there is no time for team members to plan deliberately during performance, which leads to no other option than ongoing adaptation of behaviours without explicit communication. According to team cognition models, this adaptive process would be based on pre-existing knowledge about the task, involving implicit coordination (Cannon-Bowers & Bowers, 2006). But, then, how would players cope with uncertainty when facing emergent, unpredictable and novel situations during competitive performance?

2.3 An ecological dynamics perspective of team knowledge in sport performance

In contrast to assumptions of shared internalised knowledge, an ecological approach proposes that knowledge of the world is based upon recurrent processes of perception and action (Araújo & Davids, 2011) through which humans perceive affordances (i.e., opportunities for action) during sport performance (Araújo, Davids, Cordovil, Ribeiro, & Fernandes, 2009).

The concept of affordances presupposes that the environment is perceived directly in terms of what an organism can do with and in the environment (i.e., it is not dependent on a perceiver's expectations, nor mental representations linked to specific performance solutions, stored in memory) (Oudejans, Michaels, Bakker, & Dolné, 1996). Gibson (1979) proposed that humans can perceive the features of the environment as possibilities for action. Thus, players can detect information from patterned energy arrays in the environment in terms of their own characteristics (e.g., individual height, in basketball)(Cordovil et al., 2009) or in terms of their action capabilities (e.g., perceiving a defender's most advanced foot invites the attacker to drive an attack to that side) (Esteves, Oliveira, & Araújo, 2011).

This information constrains behaviour by providing affordances or behavioural possibilities for decision-making (Fajen, Riley, & Turvey, 2008).

In relation to the role of knowledge, Gibson (1966) distinguished between two types – “knowledge of” and “knowledge about” the environment. “Knowledge of” the environment refers to the ability to complete an action by detecting the surrounding informational constraints in order to regulate behaviours, specifically through the perception of affordances. This is possible because key properties of the environment can be perceived directly, on the basis of information available, and not indirectly, on the basis of organising internal mental representations of the world (Araújo, et al., 2009).

Previous empirical work has provided some examples of adaptive behaviour during competitive and dynamic sporting contexts. Passos et al. (2011) showed that the co-adaptive behaviours emerging between teammates in a sub-phase of Rugby Union was predicated on context-dependent informational fields such as relative positioning to nearest defenders. The interpersonal distance found between attackers was significantly different according to their distance to the defensive line. Lower values of distance to opponents constrained the attackers to attain higher values of interpersonal distances. Travassos et al. (2012) demonstrated that the interception of a passing ball in futsal (indoor football) was constrained by spatial relations between key features of the environment, like the defender’s distance to the ball trajectory and the kinematic properties of the ball. Both examples highlight how successful coordination, whether at team or individual level, was supported by perception of relevant information that provides affordances, or, in Gibson’s words, “knowledge of” the environment.

“Knowledge about” the environment refers to the perception of language (e.g., from the coach), pictures and videos (e.g., from the opponents) or other symbols that facilitate access to absent information sources (Araújo & Davids, 2011; Araújo, et al., 2009). It constitutes an indirect perception (Araújo, et al., 2009) because the perception of the word “ball” which is a representation of an actual ball, is a medium to talk about a to-be-directly-perceived ball. An example of this kind of knowledge might involve the verbal explanation of one player about how and when to act in a given game situation during a team meeting. This is a typical situation in team sports preparation where knowledge is shared, presupposing the notion of collective internalisation, with a coherent sharing of the same mental representations between all teammates to underpin coordination. However, the role of this type of knowledge is to make others aware and to constrain action initiation (Araújo, et al., 2009) but only prior to actual competitive performance, before perception of information, and action occurs. Moreover, tactical skills cannot be captured by verbal reports (Araújo, Travassos, & Vilar, 2010; Sutton, 2007). Previous research in cricket and baseball showed that performers can actually do more than they can tell (Mann, Abernethy, & Farrow, 2010; Oudejans, et al., 1996) and that when asked to describe past performances they are usually inaccurate (Araújo, et al., 2009). Other examples have highlighted existing differences between making verbal judgements about affordances and actually acting on them (Pepping & Li, 2005). There is an interdependency between perception and action (Davids, Kingsbury, Bennett, & Handford, 2001) and clear differences between verbalizing and acting (Araújo, et al., 2010).

Verbalizing and reflecting about their own performance may help individuals to become more attuned to important informational constraints that they may encounter in future competitive performance. However, there is still little firm evidence to conceive this type of knowledge as a collectively internalised mechanism explaining how all team members represent the unique and specific actions-to-be-performed (as well as an opponent's actions), in correspondence with their unique perceptions of the competitive performance environment.

2.3.1 Shared affordances as an information network for team coordination

Alternatively, the control of action can be regulated through perception of affordances in a performance context (Fajen, et al., 2008). Examples of affordance-based coordination have been reported in studies of performance in basketball (Esteves et al., 2012; Esteves, et al., 2011), futsal (Travassos, Araújo, Davids, et al., 2012; Vilar, Araújo, Davids, & Travassos, 2012), Rugby

Union (Correia, Araújo, Craig, & Passos, 2011; Passos et al., 2008) and Association Football (Duarte et al., 2010; Pepping, Heijmerikx, & Poel, 2011). Affordances can be perceived because they are specified in patterns of energy available to perceptual systems (Fajen, et al., 2008; Gibson, 1979; Scarantino, 2003), allowing performers to explore and detect the relevant information to support action (Araújo, et al., 2005; Oudejans, et al., 1996).

Reed's conception of affordances (Reed, 1996) is most important in an ecological approach. He argued that affordances are resources in the environment, properties of objects that might be exploitable by an individual. These resources in the environment have incurred selection pressures on individuals, causing them to evolve perceptual systems to perceive them. Those resources, that some group of individuals evolve the ability to perceive, are affordances for members of that group.

From this viewpoint, affordances are collective environmental resources that exist prior to the individuals that came to perceive and use them. Collective affordances can be perceived by a group of individuals trained to become perceptually attuned to them. In collective sports, both teams in opposition have the same objective (i.e., to overcome the opposition and win). Hence, the perception of collective affordances acts as a selection pressure for overcoming opponents, and achieving successful performance. In this sense, collective affordances are sustained by common goals between players of the same team (i.e., they are team specific) who act altruistically to achieve success for the group.

Collective affordances can be specified by generated information sources from the positioning of teammates and opponents, motion directions and changes in motion, used to govern a team's coordination tendencies (Duarte, Araújo, Correia, & Davids, 2012; Duarte et al., 2012; Passos, et al., 2008). Thus, players can communicate by presenting affordances for each other (Vilar, Araújo, Davids, & Button, 2012) (whether consciously or not) by performing actions like passing the ball or running into an open space. These include the affordances another actor can provide under a given set of environmental conditions (i.e., affordances for others) and the affordances another actor's actions afford a perceiver (i.e., affordances of others) (Passos, Cordovil, Fernandes, & Barreiros, 2012). Therefore, by perceiving and using affordances for and affordances of others, players can share affordances and this helps to explain how teammates are able to control their actions in a coordinated way.

There is evidence supporting the idea that humans can be very accurate at perceiving another person’s action capabilities (Mark, 2007; Stoffregen, Gorday, & Sheng, 1999) and even the intentions of others (Runeson & Frykholm, 1981; Runeson & Frykholm, 1983). Examples of controlled action by perception of shared affordances in team ball sports have been reported in research in Rugby Union. Passos, et al. (2012) showed that the precise moment of a pass was decided according to the position of a tackler and to his possibilities of tackling the ball carrier. This study exemplified the perception of affordances from an opponent. The same rule can be applied for the perception of affordances from a teammate who, for example, has occupied a clear space providing the ball carrier with an opportunity to pass. Correia, Araújo, Cummins, and Craig (2012) showed how the decisions of running, passing short or passing long for an attacker were constrained by self-affordances and affordances available for his teammates.

From this perspective, team coordination depends on being collectively attuned to shared affordances founded on a prior platform of communication or information exchange. Through practice, players become perceptually attuned to affordances of others and affordances for others during competitive performance and undertake more efficient actions (Vicente & Wang, 1998) by adjusting their behaviours to functionally adapt to those of other teammates and opponents. This enables them to act coherently with respect to specific team task goals (Duarte, Araújo, Correia, et al., 2012).

2.3.2 Establishing interpersonal synergies for team coordination

So far, we have provided explanations on how the decisions and actions of players continually constrain and are constrained by the actions of their teammates and opponents towards the goals of the collective.

Concepts from application of dynamical systems theory to the study of movement coordination contribute to this alternative framework for understanding team coordination. Insights from Bernstein suggested that independently controllable movement system degrees of freedom (dof) could be coupled to form synergies that regulate each other without the need for individuals to control each single dof separately (Bernstein, 1967; Newell & Vaillancourt, 2001; Riley, et al., 2011; Turvey, 1990). This idea is mirrored in team sports, viewed as dynamical systems composed of many interacting parts (e.g., players, ball, referees, pitch dimensions) (Davids, Araújo, & Shuttleworth, 2005; Glazier, 2010). The numerous linkages between the players as collective system dofs (regarded as the numerous individual possibilities for action that emerge during competitive performance) requires the reduction of system dimensionality by harnessing the capacity for system re-organisation into structures that are specific to a particular task (Marsh, Richardson, & Schmidt, 2009; Passos et al., 2009; Riley, Shockley, & Orden, 2012). These structures, also known as coordinative structures or synergies (Davids, Button, Araújo, Renshaw, & Hristovski, 2006; Kelso, 1998), allow individuals in a team to act as collective sub-units (Kelso, 1998, 2012; Riley, et al., 2011) at the level of interpersonal interactions (Marsh, et al., 2009).

Specific constraints like the players' individual characteristics, a nation's traditions in a sport, strategy, coaches' instructions, etc., may impact on the functional and goal-directed synergies formed by the players to shape a particular performance behaviour. These informational constraints shape shared affordances available for perceptual systems, viewed as crucial for the assembly of synergies, that support the reduction of the number of independent dofs and enable fast, regulating actions (Riley, et al., 2012). Another feature of a synergy is the ability of one of its components (e.g., a player) to lead changes in others (Kelso, 2012; Riley, et al., 2011). Thus, the decisions and actions of the players forming a synergy should not be viewed as independent. In this context, social interpersonal synergies can be proposed to explain how multiple players can act in accordance with changing dynamic environments within fractions of a second. Let us re-consider the example of performing an indirect free-kick in football. If, during the run-up to the ball, the player perceives that his teammates are undertaking different moves from those previously rehearsed (due to unpredictable constraints like an effective blocking movement by opponents) he/she might choose to shoot directly at goal instead of crossing the ball.

Therefore, the coupling of players' dofs into interpersonal synergies is based upon a social perception-action system that is supported by the perception of shared affordances.

Bourbousson, Sève, et al. (2010b) reported examples of interpersonal synergies emanating from patterned behaviours of two basketball teams. They observed differences between defending teams in values for distances to immediate opponents by analysing stretch indexes, valid compound measures that capture interpersonal interactions of teammates. Paradoxically, in a companion study of the same basketball contexts, fewer spatial-temporal couplings between players' displacements (assessed by measuring the relative phase of all possible intra-team dyadic relations) were identified, supporting data from the associated study discussed earlier in section 2 (Bourbousson, Sève, & McGarry, 2010a). However, these two studies appeared to present contradictory rationalisation of the same phenomenon, with two contrasting conceptual approaches to team coordination used. While we agree that couplings between teammates may differ in strength during performance, it is not possible that players' actions can be independent in teams that exhibit co-adaptive behaviours. Further investigations need to clarify the merits of their interpretation of shared team coordination.

2.4 Conclusions and practical implications

In this article we have highlighted some inconsistencies in the conceptualisation of the idea of shared knowledge for understanding coordination in sports teams. Alternatively, we proposed an ecological dynamics approach as a useful theoretical framework to explain coordination in collective systems. We argued that team coordination is guided through perception and use of shared affordances, not by products of a mind, the environment or a stimulus (Riley, et al., 2012).

This view has major implications for designing experimental research in the field of team performance. Task designs need to focus on the player-

player-environment interactions that can be captured through compound variables specifying functional collective behaviours of sports teams (e.g., geometrical centres, stretch indexes, etc.) (Duarte, Araújo, Correia, et al., 2012) underpinned by interpersonal synergies created between players. Variations in such measures may express intra-team coordination processes as a consequence of cooperative goal-directed behaviours (Duarte, Araújo, Freire, et al., 2012). Interpretations in light of a shared affordances approach can explain how the intertwined perception-action processes of team members may form the basis of collective behavioural patterns under a specific set of constraints.

Training methods in team sports should promote the exploitation of constraints and the development of shared affordances through exploration of performance solutions. Small-sided and conditioned games may represent an excellent vehicle for the acquisition of shared affordances during practice (Davids, Araújo, Correia, & Vilar, 2013).

2.5 References

Araújo, D., & Davids, K. (2011). What exactly is acquired during skill acquisition? *Journal of Consciousness Studies, 18*(3-4), 7-23.

Araújo, D., Davids, K., Cordovil, R., Ribeiro, J., & Fernandes, O. (2009). How does knowledge constrain sport performance? An ecological perspective. In D. Araújo, H. Ripoll & M. Raab (Eds.), *Perspectives on cognition and action in sport* (pp. 119-131). New York: Nova Science Publishers, Inc.

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*, 653-676.

Araújo, D., Davids, K., & Serpa, S. (2005). An ecological approach to expertise effects in decision making in a simulated sailing regatta. *Psychology of Sport and Exercise, 6*, 671-692.

Araújo, D., Travassos, B., & Vilar, L. (2010). Tactical skills are not verbal skills: A comment on Kannekens and colleagues. *Perceptual and Motor Skills, 110*(3), 1086-1088.

Bernstein, N. (1967). *The coordination and regulation of movements*. Oxford: Pergamon Press.

Blickensderfer, E. L., Reynolds, R., Salas, E., & Cannon-Bowers, J. A. (2010). Shared Expectations and Implicit Coordination in Tennis Doubles Teams. *Journal of Applied Sport Psychology, 22*(4), 486-499.

Bourbousson, J., Poizat, G., Saury, J., & Seve, C. (2010). Team coordination in Basketball: description of the cognitive connections among teammates. *Journal of Applied Sport Psychology, 22*(2), 150-166.

Bourbousson, J., Poizat, G., Saury, J., & Seve, C. (2011). Description of dynamic shared knowledge: An exploratory study during a competitive team sports interaction. *Ergonomics, 54*(2), 120-138.

Bourbousson, J., Poizat, G., Saury, J., & Seve, C. (2012). Temporal Aspects of Team Cognition: A Case Study on Concerns Sharing Within Basketball. *Journal of Applied Sport Psychology, 24*(2), 224-241.

Bourbousson, J., Sève, C., & McGarry, T. (2010a). Space-time coordination dynamics in basketball: Part 1. intra- and inter-couplings among player dyads. *Journal of Sports Sciences, 28*(3), 339-347.

Bourbousson, J., Sève, C., & McGarry, T. (2010b). Space-time coordination dynamics in basketball: Part 2. The interaction between the two teams. *Journal of Sports Sciences, 28*(3), 349-358.

Cannon-Bowers, J. S., & Bowers, C. (2006). Applying work team results to sports teams: opportunities and cautions. *International Journal of Sport and Exercise Psychology, 4*(4), 447-462.

Cooke, N., Salas, E., Kiekel, P., & Bell, B. (2004). Advances in measuring team cognition. In B. Bell, E. Salas & S. Fiore (Eds.), *Team cognition: Understanding the factors that drive process and performance* (pp. 83-106). Washington DC: APA.

Cordovil, R., Araújo, D., Davids, K., Gouveia, L., Barreiros, J., Fernandes, O., et al. (2009). The influence of instructions and body-scaling as constraints on decision-making processes in team-sports. *European Journal of Sport Science, 9*(3), 169-179.

Correia, V., Araújo, D., Craig, C., & Passos, P. (2011). Prospective information for pass decisional behavior in rugby union. *Human Movement Science, 30*, 984-997.

Correia, V., Araújo, D., Cummins, A., & Craig, C. M. (2012). Perceiving and Acting Upon Spaces in a VR Rugby Task: Expertise Effects in Affordance Detection and Task Achievement. *Journal of Sport & Exercise Psychology, 34*(3), 305-321.

Correia, V., Araújo, D., Davids, K., Fernandes, O., & Fonseca, S. (2011). Territorial gain dynamics regulates success in attacking sub-phases of team sports. *Psychology of Sport and Exercise, 12*(6), 662-669.

Davids, K., & Araújo, D. (2010). The concept of "Organismic Asymmetry" in sport science. *Journal of Science and Medicine in Sport, 13*, 633-640.

Davids, K., Araújo, D., Button, C., & Renshaw, I. (2007). Degenerate brains, indeterminate behavior, and representative tasks: implications for experimental design in sport psychology research. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of Sport Psychology* (3rd ed., pp. 224-244). New Jersey: John Wiley & Sons, Inc.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews, 41*(3), 154-161.

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of dynamical system theory to Football. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science & Football V* (pp. 556-569). Oxon: Routledge.

Davids, K., Button, C., Araújo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human movement studies. *Adaptive Behavior, 14*, 73-94.

Davids, K., Kingsbury, D., Bennett, S., & Handford, C. (2001). Information-movement coupling: implications for the organization of research and practice during acquisition of self-paced extrinsic timing skills. [Review]. *Journal of Sports Sciences, 19*(2), 117-127.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sport teams as superorganisms: implications of biological models for research and practice in team sports performance analysis. *Sports Medicine, 42*(8), 633-642.

Duarte, R., Araújo, D., Freire, L., Folgado, H., Fernandes, O., & Davids, K. (2012). Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. *Human Movement Science, 31*(6), 1639-1651.

Duarte, R., Araújo, D., Gazimba, V., Fernandes, O., Folgado, H., Marmeleira, J., et al. (2010). The ecological dynamics of 1v1 sub-phases in association football. *The Open Sports Sciences Journal, 3*, 16-18.

Eccles, D. (2010). The coordination of labour in sports teams. *International Review of Sport and Exercise Psychology, 3*(2), 154-170.

Eccles, D., & Groth, P. T. (2006). Wolves, bees, and football: Enhancing coordination in sociotechnological problem solving through the study of human and animal groups. *Computers in Human Behavior, 23*, 2778-2790.

Eccles, D., & Tenenbaum, G. (2004). Why an expert team is more than a team of experts: A social-cognitive conceptualization of team coordination and communication in sport. *Journal of Sport & Exercise Psychology, 26*, 542-560.

Esteves, P., Araújo, D., Davids, K., Vilar, L., Travassos, B., & Esteves, C. (2012). Interpersonal dynamics and relative positioning to scoring target of performers in 1 vs. 1 sub-phases of team sports. *Journal of Sports Sciences, 30*(12), 1285-1293.

Esteves, P., Oliveira, R., & Araújo, D. (2011). Posture-related affordances guide attacks in basketball. *Psychology of Sport and Exercise, 12*, 639-644.

Fajen, B. R., Riley, M. A., & Turvey, M. (2008). Information affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*(1), 79-107.

Ferrario, V. F., Sforza, C., Dugnani, S., Michielon, G., & Mauro, F. (1999). Morphological variation analysis of the repeatability of soccer offensive schemes. *Journal of Sports Sciences, 17*(2), 89-95.

Fiore, S., & Salas, E. (2006). Team cognition and expert teams: developing insights from cross-disciplinary analysis of exceptional teams. *International Journal of Sport and Exercise Psychology, 4*(4), 369-375.

Folgado, H., Lemmink, K., Frencken, W., & Sampaio, J. (2012). Length, width and centroid distance as measures of teams tactical performance in youth football. *European Journal of Sport Science, iFirst article*, 1-6.

Frencken, W., De Poel, H., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences, 30*(12), 1207-1213.

Gibson, J. (1966). *The senses considered as perceptual systems*. Boston: MA: Houghton Mifflin.

Gibson, J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Glazier, P. S. (2010). Game, set and match? Substantive issues and future directions in performance analysis. *Sports Medicine, 40*(8), 625-634.

Kelso, J. A. S. (1998). From Bernstein's physiology of activity to coordination dynamics. In M. Latash (Ed.), *Progress in motor control. Bernstein's traditions in movement studies* (pp. 203-219). Champaign, IL: Human Kinetics.

Kelso, J. A. S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 367*, 906-918.

Kozlowski, S. W. J., & Ilgen, D. R. (2006). Enhancing the Effectiveness of Work Groups and Teams. [Article]. *Psychological Science in the Public Interest, 7*(3), 77-124.

Lausic, D., Tennebaum, G., Eccles, D., Jeong, A., & Johnson, T. (2009). Intrateam Communication and Performance in Doubles Tennis. *Research Quarterly for Exercise and Sport, 80*(2), 281-290.

Mann, D., Abernethy, B., & Farrow, D. (2010). Action specificity increases anticipatory performance and the expert advantage in natural interceptive tasks. [Research Support, Non-U.S. Gov't]. *Acta Psychologica, 135*(1), 17-23.

Mark, L. S. (2007). Perceiving the Actions of Other People. [Article]. *Ecological Psychology, 19*(2), 107-136.

Marsh, K., Richardson, M., & Schmidt, R. (2009). Social connection through joint action and interpersonal coordination. *Topics in Cognitive Science, 1*, 320-339.

Mohammed, S., & Dumville, B. (2001). Team mental models in a team knowledge framework: expanding theory and measurement across disciplinary boundaries. *Journal of Organizational behavior, 22*, 89-106.

Mohammed, S., Klimoski, R., & Rentsch, J. (2000). The measurement of team mental models: we have no shared schema. *Organizational Research Methods, 3*(2), 123-165.

Newell, K., & Vaillancourt, D. (2001). Dimensional change in motor learning. *Human Movement Science, 20*(4-5), 695-715.

Oudejans, R., Michaels, C., Bakker, F., & Dolné, M. (1996). The relevance of action in perceiving affordances: perception of catchableness of fly balls. *Journal of Experimental Psychology: Human Perception and Performance, 22*(4), 879-891.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Milho, J., & Serpa, S. (2008). Information-governing dynamics of attacker-defender interactions in youth Rugby Union. *Journal of Sports Sciences, 26*(13), 1421-1429.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Serpa, S., & Milho, J. (2009). Interpersonal pattern dynamics and adaptative behavior in multiagent neurobiological systems: conceptual model and data *Journal of Motor Behavior, 41*(5), 445-459.

Passos, P., Cordovil, R., Fernandes, O., & Barreiros, J. (2012). Perceiving affordances in rugby union. *Journal of Sports Sciences, 30*(11), 1175-1182.

Passos, P., Milho, J., Fonseca, S., Borges, J., Araujo, D., & Davids, K. (2011). Interpersonal Distance Regulates Functional Grouping Tendencies of Agents in Team Sports. [Article]. *Journal of Motor Behavior, 43*(2), 155-163.

Pepping, G.-J., Heijmerikx, J., & Poel, H. J. d. (2011). Affordances shape kick behaviour in association football: effects of distance and social context. *Revista de Psicologia del Deporte, 20*(2), 709-727.

Pepping, G.-J., & Li, F.-X. (2005). Effects of response task on reaction time and the detection of affordances. *Motor Control, 9*, 129-143.

Poizat, G., Bourbousson, J., Saury, J., & Seve, C. (2012). Understanding team coordination in doubles table tennis: Joint analysis of first- and third-person data. *Psychology of Sport and Exercise, 13*(5), 630-639.

Poizat, G., Bourbousson, J., Saury, J., & Sève, C. (2009). Analysis of contextual information sharing during table tennis matches: An empirical study of coordination in sports. *International Journal of Sport and Exercise Psychology, 7*(4), 465-487.

Reed, E. S. (1996). *Encountering the world: Toward an ecological psychology*. Oxford: Oxford University Press.

Reimer, T., Park, E., & Hinsz, V. (2006). Shared and coordinated cognition in competitive and dynamic task environments: an information-processing perspective for team sports. *International Journal of Sport and Exercise Psychology, 4*, 376-400.

Rentch, J., & Davenport, S. (2006). Sporting a new view: team member schema similarity in sports. *International Journal of Sport and Exercise Psychology, 4*(4), 401-421.

Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R. L., & Schmidt, R. C. (2007). Rocking together: dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science, 26*, 867-891.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Riley, M., Shockley, K., & Orden, G. V. (2012). Learning from the body about the mind. *Topics in Cognitive Science, 4*, 21-34.

Runeson, S., & Frykholm, G. (1981). Visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance, 7*(4), 733-740.

Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person-and-action perception: Expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General, 112*(4), 585-615.

Salas, E., Cooke, N. J., & Rosen, M. A. (2008). On teams, teamwork, and team performance: discoveries and developments. *Human Factors, 50*(3), 540-547.

Salas, E., Rosen, M. A., Burke, C. S., Nicholson, D., & Howse, W. R. (2007). Markers for enhancing team cognition in complex environments: The power of team performance diagnosis. *Aviation Space and Environmental Medicine, 78*(5), B77-B85.

Scarantino, A. (2003). Affordances explained. *Philosophy of Science, 70*, 946-961.

Schmidt. (1975). A schema theory of discrete motor skill learning. *Psychological Review, 82*(4), 225-260.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences, 10*(2), 70-76.

Shearer, D. A., Holmes, P., & Mellalieu, S. D. (2009). Collective efficacy in sport: the future from a social neuroscience perspective. *International Review of Sport and Exercise Psychology, 2*(1), 38-53.

Stoffregen, T., Gorday, K., & Sheng, Y.-Y. (1999). Perceiving affordances for another person's actions. *Journal of Experimental Psychology: Human Perception and Performance, 25*(1), 120-136.

Sutton, J. (2007). Batting, habit and memory: the embodied mind and the nature of skill. *Sport in Society, 10*(5), 763-786.

Tenenbaum, G., Lausic, D., & Eccles, D. (2005). Communication and coordination: Essentials for team expertise. *Journal of Sport & Exercise Psychology, 27*, S22.

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychology of Sport & Exercise, 13*(2), 216-223.

Travassos, B., Araújo, D., Duarte, R., & McGarry, T. (2012). Spatiotemporal coordination behaviors in futsal (indoor football) are guided by informational game constraints. *Human Movement Science, 31*(4), 932-945.

Turvey, M. (1990). Coordination. *American Psychologist, 45*(8), 938-953.

Vicente, K., & Wang, J. (1998). An ecological theory of expertise effects in memory recall. *Psychological Review, 105*(1), 33-57.

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine, 42*(1), 1-10.

Vilar, L., Araújo, D., Davids, K., & Travassos, B. (2012). Constraints on competitive performance of attacker-defender dyads in team sports. *Journal of Sports Sciences, 30*(5), 459-469.

Ward, P., & Eccles, D. (2006). A commentary on "team cognition and expert teams: emerging insights into performance for exceptional teams". *International Journal of Sport and Exercise Psychology, 4*, 463-483.

Chapter 3

Practice Effects on Emergent Intra-team Synergies in Football [4]

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Abstract

Developing synchronised player movements during match play is a common goal for coaches of team games. An ecological dynamics approach advocates that intra-team synchronization is governed by locally created information, which specifies shared affordances responsible for synergy formation. To verify this claim we evaluated emergent coordination tendencies in two newly-formed teams of recreational players during football practice games, weekly, for thirteen weeks. We investigated practice effects on emergence of player (Pc) and team (Tc) couplings captured as near in-phase modes of coordination during the teams' ebb-and-flow movements. Delays in readjusting co-positioning (Rd) between coupled players were assessed as a measure of synchronization speed. Results showed that synergies were formed and dissolved rapidly as a result of the dynamic creation of informational properties, as shared affordances between performers. Synergy formation followed an identical structure for all players, highlighting existence of a coordinated search for synchrony during play. Practicing once a week led to slight decreases in Rd, enabling faster regulation of coordinated team actions. Mean values of Pc and Tc were unchanged. No relationship between Pc, Tc and Rd was found for team performance indicators (shots, ball possession and ball recoveries). Findings open up new perspectives in monitoring team tactical performance.

Keywords: team synchrony; collective coordination; shared affordances, tactical learning.

[4] *Under Review*

3.1 Introduction

In team games like association football the rhythmic ebb-and-flow of player movements in competing teams represent the patterns formed when attacking and defending. Such movements occur fundamentally in the goal-to-goal direction and have been previously described in analyses of small-sided games (e.g., Frencken et al., 2011) and regular 11-a-side competitive fixtures (e.g., Frencken et al., 2012; Lames et al., 2010).

In the coaching literature it is implicit that rhythmic and coordinated ebb-and-flow movements of players on a team (i.e., advancing up-field to attack and moving back to protect the goal and defend) require coordinated movements of performers to support the necessary team cohesion to outperform opponents (Bangsbo & Peitersen, 2002, 2004; Hughes, 1994; Worthington, 1974). Evidence for this assumption is exemplified by data from the study of Duarte, Araújo, et al. (2013) where large synergistic relations in professional football teams were observed (through cluster phase measures), mainly in the longitudinal direction on-field.

Synergies are temporary assemblages of components constrained to behave as a single functional unit (Kelso, 2012; Riley et al., 2012). The notion of a synergy has existed in the human movement sciences for over a century (Latash et al., 2007), most commonly associated with the problem of coordination by the central nervous system of redundant motor system degrees of freedom to regulate functional behaviours (Bernstein, 1967). The formation of synergies between parts of the body during goal achievement (Davids et al., 2006; Kelso, 1998) led to a reduction in system dimensionality by harnessing degrees of freedom that were specific to a particular task, while abandoning nonessential ones (Beek et al., 2003).

Synergies formed in complex systems are not static representational structures (e.g., motor programs) but compensatory low-dimensional relations (Kelso, 2009) that continuously emerge and change through inherent self-organization processes (Kelso, 1995, 2012). They have the ability to compensate for any perturbations to one system component by adjustment in remotely linked parts to preserve its functional integrity (Kelso, 2012; Riley et al., 2011; Riley et al., 2012). For instance, during a fast break attack in team sports, the movements of attackers towards the opposition goal may leave gaps in remaining team sectors that can be compensated by teammates readjusting their movement direction and speed to link up with the forwards. In this sense, between-individual interpersonal interactions display the same hallmark properties of synergy formation of within-individual interactions (self-movement control) (Riley et al., 2012). For example, Duarte, Travassos, et al. (2013) identified different influences in football teams' coordination tendencies during football small-sided practice games according to the defensive playing method adopted (man-to-man vs. zone defence). Folgado et al. (2014) also found that playing against higher-level opponents constrained higher intra-team movement synchronization, especially in the goal-to-goal direction of the field. These studies exemplified how different coordination tendencies may emerge in team players by adoption of different strategies against different opponents.

An important concept in explanations of synergy formation in team sports is *affordances*. Affordances are information sources in a performance environment, which may be directly perceived in inviting specific actions from individuals (Gibson, 1979). Information is perceived as opportunities for action and emerges from the continuous interactions of an athlete with key features of a performance environment studied at the ecological scale of analysis (Araújo et al., 2006; Fajen et al., 2009). Humans can perceive affordances for themselves and also another individual's affordances and intentions, regulating behaviours accordingly so that cooperative actions eliminate the unnecessary degrees of freedom to achieve a common intended goal (Mark, 2007; Marsh et al., 2006; Stoffregen et al., 1999). For instance, perceiving the possibility to move towards the opposition goal also implies perceiving the same possibilities and intentions in teammates so that team cohesiveness can be maintained. According to Gibson (1979) *"behaviour affords behaviour (p. 135)"* signifying how coordination tendencies between team players may emerge through shared affordances and intentions during competitive performance. Synergies emerge from the platform of a shared (mainly visual and non-verbal) communication channel used by teammates to collectively perceive affordances for interactive behaviours (Silva et al., 2013). Shared affordances are crucial in synergy formation since they support the reduction in the number of independent degrees of freedom, enabling fast regulating actions (Riley et al., 2011). In football teams this process could be predicated, for instance, on the multitude of coupled movement behaviours between teammates, resulting in reduced times emerging from their co-positioning during the rhythmic ebb-and-flow of competitive matches.

Despite the importance of such proposals, to the best of our knowledge there have been no attempts to capture the nature of emergent synergy formation in football teams during competitive matches, or effects of practice on emergent intra-team couplings. If synergies form the basis of team performance, and if team performance may improve with practice, it is plausible to expect that emergent couplings between players could also be susceptible to improvement. Relatedly, it is unknown whether improvements to the number of emergent couplings between teammates can constrain efficacy of attacking and defending. Considering that teammates share the same objectives (McGarry et al., 2002) hypothetically, the establishment of stronger synergies would lead to higher levels of team coordination, impacting positively on team performance indicators typically associated with success, like the number of shots at goal (Lago et al., 2010; Szwarc, 2007) percentage of ball possession (Lago & Dellal, 2010) in attack, and the number of ball recoveries (Almeida et al., 2014) in defence.

In this study we sought to describe the emergence of intra-team synergies from the coordinated movements of players and to verify whether the number of stronger emergent couplings (associated with successful performance) could be improved with practice. The impact of intra-team coordination tendencies on attacking and defending performance indicators was also analysed. We expected that the number of strong emergent synergies (per player and team) would augment with practice and enable fast co-positioning movements between teammates, possibly supporting more efficient attacking (i.e., more ball possession and shots) and defensive actions (i.e., more ball recoveries).

3.2 Materials and methods

3.2.1 Participants

Twenty-nine undergraduate students from the Faculty of Sports of Porto University were recruited to participate in this study (mean ± standard deviation – age: 20.21±1.74 yrs; height: 178.07±5.87 cm; weight: 73.52±7.47 kg). Participants were enrolled in football classes for 2 hours, once a week for fifteen weeks, as part of their curricula on a Sports Science degree.

Participants' previous experiences in football practices were varied, ranging from 0 to 15 years (6.14±4.95 yrs). Ten students in our sample had never participated in structured football practices or competitive fixtures. At most, they had only participated in such activities for a maximum period of three years in early childhood. The remaining 19 students had experience levels ranging from 4 to 15 years, comprising football practice and competition, with seven students still playing at a senior amateur level, outside faculty classes. The study protocol conformed to the ethical standards of the declaration of Helsinki and was approved by the local ethics committee.

3.2.2 Experimental design

In the first football class students were assembled into two technically equivalent teams that played under two different formations (team A: 1-4-3-3; team B: 1-4-4-2). Teams A and B were composed of eleven players plus five and four reserves, respectively. An accredited UEFA-B level teacher coordinated the football classes and possessed ten years experience in teaching and coaching youth players at club and high-school levels. The constitution of both teams and the assignment of positional roles to players was based on: (i) previous experiential knowledge of the teacher about the students' skills obtained during football classes in the previous semester[5], (ii)

[5] The program in the 1st semester comprised reduced numbers in game formats typically used in youth football developmental programs (5-a-side and 7-a-side), whereas the 2nd semester classes addressed the structural organization of regular 11-a-side football teams.

participants' previous experience in football practices and competitive fixtures, outside faculty classes, (iii) preferred positional roles, and (iv), preferred foot. The goalkeepers in the sample volunteered to assume the role as they played in that position in clubs at a regional-level outside football classes. All classes included practical activity delivered with a game-centred approach (Gabbett et al., 2009), involving the practice of small-sided games to address current football offensive and defensive strategies. The fundamental course aim was to educate students in the theoretical content of sports science sub-disciplines composing the course curricula. Participant understanding of football tactics was also often stimulated through questioning and reflection during classes and, thus, training exercises were interspersed with large instructional periods that allowed participants to recover between exercise bouts. After this initial period (of approximately 50 minutes duration) participants played 11v11 games divided into two halves of fifteen minutes, separated by seven minutes of passive recovery and rehydration. These matches formed an internal class tournament, where points were allocated to winning teams throughout the semester. Students were allowed to change their positional role when performing in the first part of the class, but not during the tournament matches undertaken at the end of the class.

3.2.3 Data collection

During each match, each player carried an unobtrusive global positioning tracking device (GPS) that captured the longitudinal and latitudinal movement coordinate time-series with a sampling frequency of 10 Hz (Qstarz, model: BT-Q1000eX).

Trajectories of each player were calculated using positional data from GPS devices. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). The field was calibrated with the coordinates of four GPS devices stationed in each corner, and the origin of the Cartesian coordinate system was placed at the pitch centre. Fluctuations in player positioning were reduced using a moving average filter with a time scale of 0.2 seconds and data resampling was employed to synchronise the time series of all players within each game. MatLab R2013b (The Mathworks, USA) was used to process and analyse the data.

In each match, each team was monitored for fifteen minutes of match play (team A was monitored for the first half and team B in the second half) throughout the period of fifteen weeks. A total of thirteen matches were performed and GPS data were available and analysed for twelve matches[6].

3.2.4 Variables

Synergy formation between teammates during the ebb-and-flow of competition was analysed by, first, calculating the radial distance of each player to their goal centre, over time. Given that approximately 85% of the total distance covered by each player was at low intensity running (i.e., walking or jogging, < 12 $km.h^{-1}$) and that the rate of change of the players' distances to goals rarely reached 8 $km.h^{-1}$, we used a sampling rate of 2 Hz (0.5 seconds) as a reasonable time frequency to capture this variable's time-variation.

No differentiation for the players' lateral and longitudinal movements was undertaken given that, as reported earlier, the natural rhythmic flow of a competitive game typically emerges in the goal-to-goal direction. The couplings that emerged between teammates (Pc) during such movements were taken to depict the number of synergies established by each player during attacking and defending patterns of play. Players' couplings with teammates were considered to represent the establishment of synergies (as they share the same goals) and were assessed by calculating the relative phase of all pairs (defined as two teammates co-positioning relative to each other) for distances to their own goal using a Hilbert transform (Palut & Zanone, 2005). A relative phase value between -30º to 30º (near-in-phase

[6] At weeks 8 and 11, classes did not take place due to a national public holyday and an academic event, respectively. At week 3 the final match class was not recorded with the GPS system due to severe rain that altered turf conditions, affecting participants' movements and ball bounce.

synchronisation mode) was considered to represent a strong coupling between a dyad of cooperating players (i.e., a synergy), as previously used in other studies (e.g., Folgado et al., 2014). Then, for each outfield player we recorded the number of teammates with whom they formed strong couplings (out of a maximum of 9; the goalkeeper coupling was excluded) for each time frame (i.e., twice per second). Furthermore, we noted the total number of couplings between teammates in each team (out of a maximum of 45 possible couplings) in each time frame. Team couplings (Tc) provided information on the number of synergies formed within a team that momentarily supported their collective ebb-and-flow movements between attack and defence. An example of the formation of Pc and Tc during a 6-second movement forward by an attacking team is illustrated in Figure 1.

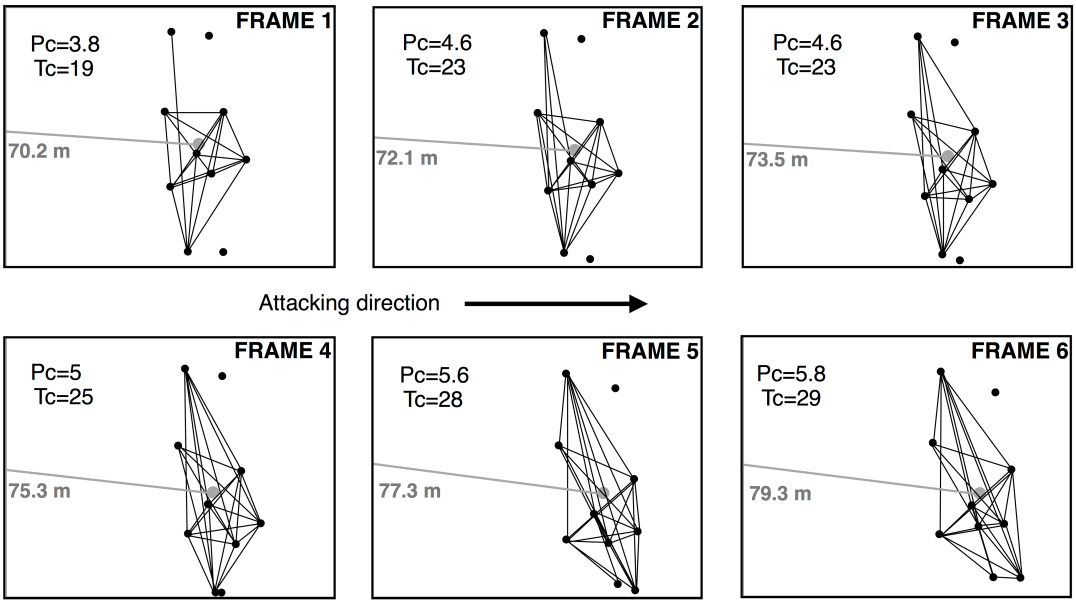

Figure 1 – Exemplar representation of one team movement towards the opposition goal and the co-positioning of players to adjust to each other's movements (6-seconds duration). The assembly of synergies is depicted, frame-by-frame, by the couplings (solid black lines) between teammates (relative phase values for their distances to goal in between -30-30º - near in-phase synchronisation mode). The grey dot and solid lines represent the team centre and its distance to the team's own goal. Pc – average number of couplings per player; Tc – total number of established couplings in the team.

The players' co-positioning delay (Rd) to adjust to teammates' movements was computed as a measure of team readiness and synchronization speed during attacking and defending patterns of play. Lower delay values indicate rapid readjustment of movements and faster spatial-temporal synchrony between players, whereas a larger readjustment delay might impede spatial-temporal synchrony of player movements. To analyse Rd, the time series of distances to goal of each dyad were lagged in time, relative to one another, for maximal agreement, reported through the highest correlation coefficient values. A windowed cross-correlation technique, with overlapping time windows that covered the whole time series (see Figure 2a for an illustration of this technique) data was then used for each player with all his nine teammates, producing a moving estimate of association and lag (Boker et al., 2002). The max lags (i.e., the lags registering the highest absolute *r*-values) were considered to represent the time delay, in seconds, between two players' co-positioning in relation to their own goal (see Figure 2b for an illustration of a delay between two teammates). The average duration of a playing sequence throughout matches ranged between 9 to 13 seconds, for both teams. Thus, a minimum window size of 20 s (40 data points) was chosen as a reasonable time window to scrutinise the coupling strength between two teammates. During such periods the probability of encompassing both attacking and defending movements was higher. A maximum lag range of 10 seconds was chosen based on the experiential knowledge of a panel of five youth coaches (coaching experience: 11.6±3.9 years in youth Football). They proposed a value for the maximum delay that could hypothetically occur between the movements of two players during a match (agreed independent of the teams disputing ball possession but not considered, from a performance point of view, as an acceptable Rd). Max lags differing from zero were considered to be positive lags, independent of the player that was temporally leading the competitive interactions. Through this process, it was generated for each player a matrix composed of nine time series with length of match duration, containing the Rd with his nine teammates (goalkeepers excluded).

Finally, performance indicators including the total number of shots, percentage of ball possession and number of direct ball recoveries (tackles and interceptions) were recorded for each team in each match.

Computation of all variables was processed in Matlab R2011a (Mathworks, USA).

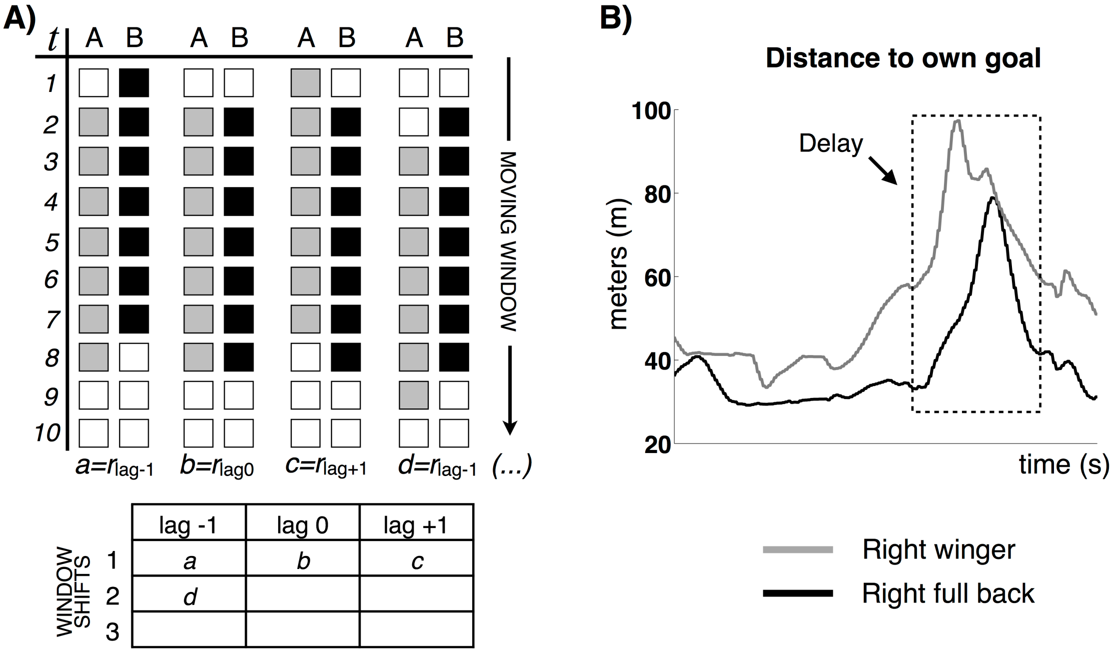

Figure 2 – A) the windowed-cross correlation technique (adapted from Boker et al., 2002). In the example provided it is used a sliding window of 7 data points and a maximum lag range of 1. B) Illustration of a time delay between two players from team B (the right-winger and fullback) during an attacking move. It is possible to see that the winger starts his movement towards the opponent's goal sooner than the fullback. The example depicts a delay of two seconds.

3.2.5 Data analysis

Descriptive statistics were performed to quantitatively describe the central tendencies (mean) and dispersion (standard deviation) of Pc and Tc during matches across time. For each player, the Rd matrix was organized, line-by-line, according to each dyad's coupling strength, i.e., from the strongest to the weakest coupling, following relative phase values. The mean Rd of the 1st and 9th most coupled teammates (of all players) are reported on Table 1 and overall mean values were illustrated throughout weeks, for each team, along with linear regression slopes and associated coefficients of determination (R^2).

Data on frequencies of shots, ball recoveries and percentage of ball possession were displayed for each match. All periods of game stoppages (i.e., ball out, fouls, etc.) were excluded from analyses (percentage of ball possession was assessed as a proportion of actual playing time).

3.3 Results

Figure 3 depicts some features of the dynamics of emergent couplings (i.e., synergies) formed between players during the ebb-and-flow movements of team A during fifteen minutes of match play (match 13, week 15). Players were, on average, coupled with six teammates (6.3±2.55) during their team's ebb-and-flow movements and oscillations in the number of couplings occurred in a similar fashion for all players (Figure 3-A). In this example the average team couplings (Tc) was approximately 32 (31.51±10.62), with values oscillating between 10 and 45 team couplings (Figure 3-B).

Mean Pc and Tc increased and decreased with no discernible pattern, not evidencing any kind of trend throughout the programme, as shown in Figures 3-C and 3-D, respectively. Pc mean values ranged between 4 to 6 couplings whereas Tc mean values situated in between 22 to 33 couplings.

Figure 4 shows that Rd values were lower for co-positioning between most coupled teammates, as expected. It is also clear that players in both teams decreased the delays between their co-positioning movements from the first to the last match. At week 1, only the first and second most coupled teammates of each player responded to each other's movements within the range of approximately one second in team A. Team B displayed even larger values of Rd for each player to their 1st and 2nd most coupled teammates. This value increased markedly from the third to the ninth most coupled teammate on both teams. Thirteen practice games later, the first seven most coupled teammates responded to each other's movements within the range of approximately one second, in both teams. Team B showed a larger Rd reduction from week 1 to week 15.

When describing the effects of practice across time, both teams have decreased the co-positioning delays to their teammates (Figure 5). In general, regression values (R^2) are low for both teams (especially for team A), independently of coupling strength. However, the slopes are consistent in sign (always negative) and in amplitude, highlighting a slight decreasing tendency in Rd across weeks. This was not a straightforward process, as teams displayed random variations across matches. A decreasing trend was more evident for team B that showed larger R^2 values, especially for the least synchronised teammates (from the 5th to the 9th most synchronised teammates).

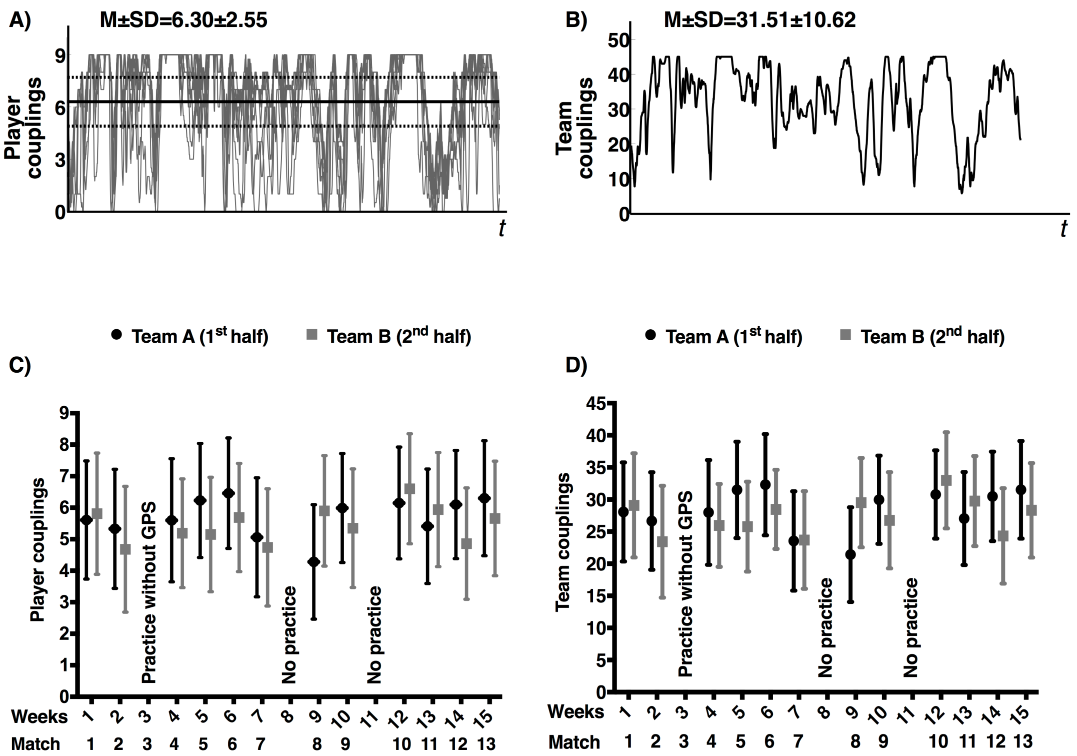

Figure 3 – Dynamics of the emergent couplings during team ebb-and-flow movements for 15 minutes of match play. A) Number of player couplings (solid and dashed lines represent means ± standard deviations respectively); B) Number of team couplings (out of 45 possible couplings); C) Effects of football practice (13 games) on mean player couplings; D) Effects of football practice on average team couplings. Error bars on C) and D) represent standard deviation.

Team tactics (1-4-3-3 or 1-4-4-2), regularity of players in team formation (i.e., playing with the same players on repeated positions) and performance indicators like percentage of ball possession, shots and ball recoveries (see Table 1) were not clearly associated with mean values of Pc and Tc. For instance, in match 6, team A presented the largest mean values of Pc and Tc. However, they achieved the same number of shots, more ball recoveries and a higher percentage of ball possession in match 8, where they registered one of the lowest mean values of Pc and Tc (see Table 1). The same happened for team B in matches 10 and 12, for example.

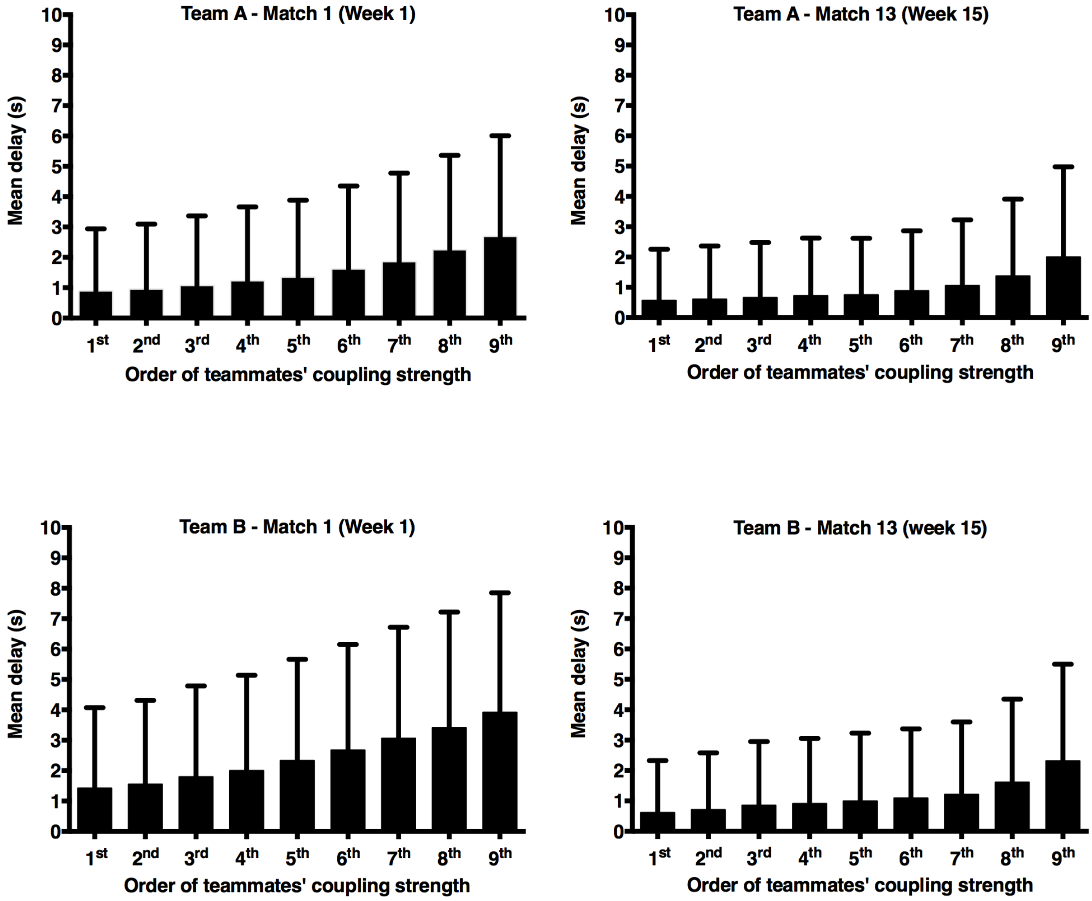

Figure 4 – Mean co-positioning delay for each player with teammates during different attacking-defending movement patterns according to the order of coupling strength (from the 1st to the 9th most coupled teammate). Error bars represent standard deviation.

However, Rd seemed to be lower for larger values of Pc and Tc and vice-versa. For example, in match 8, team A displayed the lowest value of Pc (4.28±2.54) and Tc (21.42±10.29) and the largest values of Rd (first to last most coupled teammates mean Rd: 1.12 – 3 seconds). Team B showed the lowest values of Rd on match 10 (first to last most coupled teammates mean Rd: 0.95 – 1.8 seconds) where they displayed the largest mean values of Pc (6.6±2.44) and Tc (32.98±10.46).

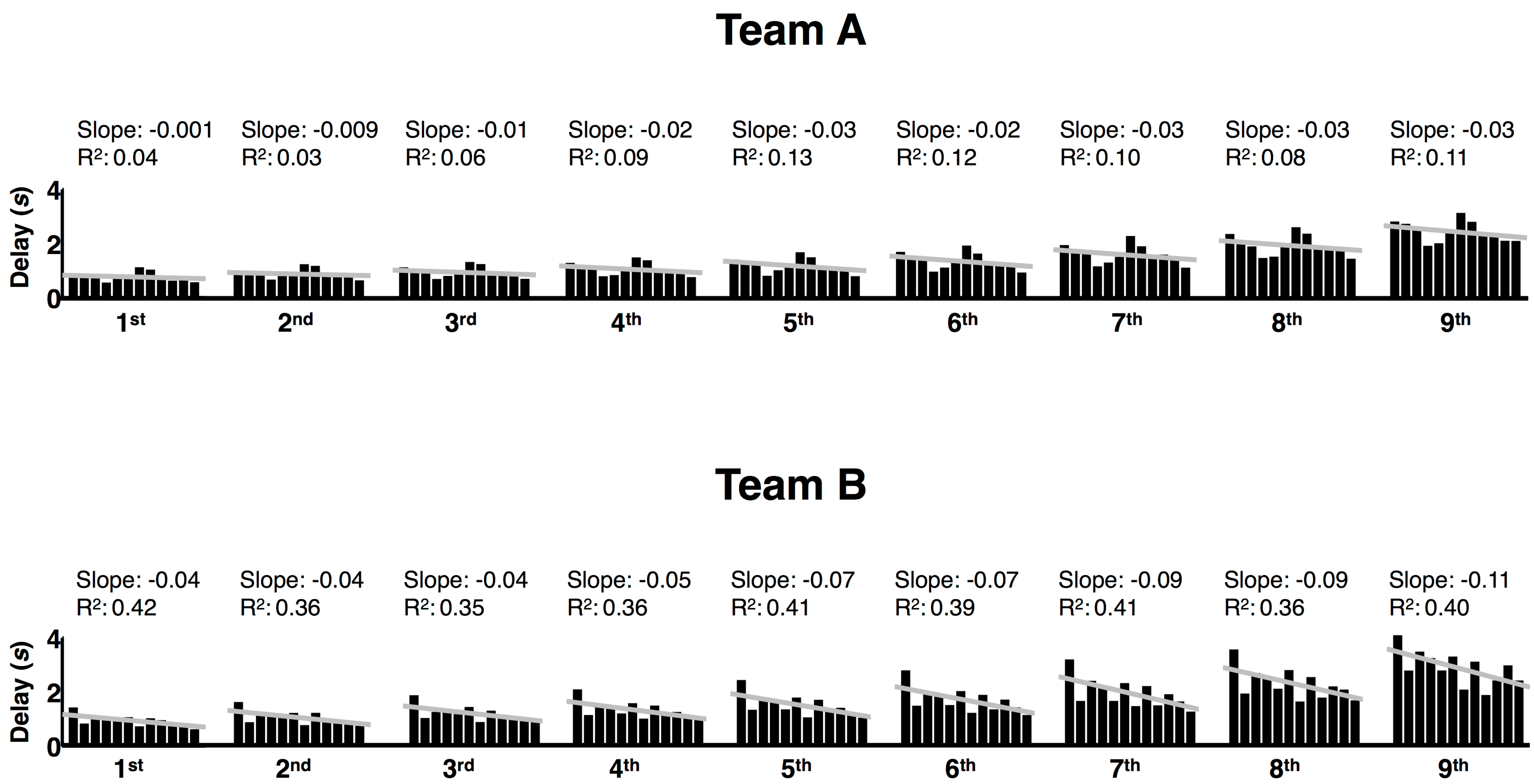

Figure 5 – Mean readjustment delay (Rd) of all players with teammates according to coupling strength level (from the 1st to the 9th most coupled teammate). Each bar depicts one practice session (i.e., one week out of a total of twelve analysed sessions). Trend lines depict the best linear fit (least squares) for delays across matches according to teammate's coupling strength level. Linear regression slopes and coefficients of determination (R^2) are displayed on top of each category. In Team A, while R^2 values are very low, the slopes are consistently negative supporting the progressive decrease on Rd.

3.4 Discussion

The main aim of this study was to characterise the emergence of intra-team synergies during the rhythmic ebb-and-flow movements of attacking and defending in football teams. We also examined effects of practice on: (i) the mean number of players' and team couplings (Pc and Tc, respectively); and (ii), the players' co-positioning movement delays (Rd). Relations of variables with attacking (shots, percentage of ball possession) and defending (ball recoveries) performance indicators were also inspected.

Results showed that synergies emerged and dissolved very quickly throughout a match, oscillating between peaks where players synchronised movements with 8-9 teammates, dropping to 2, 1 or even 0 teammates a few seconds later. This oscillating process probably corresponded to moments where teams had to readjust to new functions like, for example, switching from a backwards move during defending to a fast forward move after regaining ball possession. This assumption needs further verification, since a decrease in the number and magnitude of drops in Pc might be associated with higher team cohesiveness during match transitions.

This oscillating property of synergy formation stresses the idea that moving players provide informational properties that offer or invite actions, changing over different timescales. Switching from 9 to 0 couplings and then forming 8 – 9 couplings in a matter of seconds defines a typical process of team synchrony-asynchrony-synchrony, where players need to perceive momentarily each other's affordances and intentions (Silva et al., 2013; Silva et al., 2014) and rapidly readjust their behaviours accordingly, whenever a perturbation on team synchrony occurs (e.g., losing ball possession). Figure 1 illustrates an example of this continuous readjustment process. As some players advanced up-field, other players were compelled to follow in corresponding to team patterns of play. These team behaviours emerged from shared affordances and intentions that link players by reducing their number of action possibilities (Silva et al., 2013).

Table 1 – Frequencies of shots, ball recoveries (Ball Rec.), percentage of ball possession (Poss. %) and goals (AvB for 1st and 2nd halves); mean ± standard deviations of players' couplings (Pc), team couplings (Tc) plus readjustment delay (Rd) in seconds (for the 1st and 9th most coupled teammates) for teams A and B, in each half. The final column (PR) refers to the players' regularity in each team (i.e., the number of outfield players from the initial formations that were repeated across matches – goalkeepers excluded).

Match	1st Half						2nd Half						Goals (AvB)	PR
	Shots	Ball Rec.	Poss. (%)	Pc Team A	Tc Team A	Rd Team A	Shots	Ball Rec.	Poss. (%)	Pc Team B	Tc Team B	Rd Team B		
1	A: 0 B: 5	A: 9 B: 6	A: 38.49 B: 61.51	5.61 ±2.62	28.06 ±10.78	1st: 0.89 9th: 2.68	A: 6 B: 2	A: 9 B: 8	A: 49.62 B: 50.08	5.81 ±2.69	29.08 ±11.33	1st: 1.42 9th: 3.91	1st: 0-1 2nd: 1-1	A: 10 B: 10
2	A: 2 B: 5	A: 2 B: 5	A: 63.63 B: 36.67	5.33 ±2.64	26.64 ±10.60	1st: 0.72 9th: 2.60	A: 8 B: 1	A: 13 B: 10	A: 47.10 B: 52.90	4.68 ±2.79	23.42 ±12.17	1st: 0.82 9th: 2.66	1st: 1-0 2nd: 2-0	A: 8 B: 6
3	A: 5 B: 4	A: 9 B: 8	A: 62.78 B: 37.22	*Practice without GPS*			A: 5 B: 7	A: 4 B: 4	A: 50.40 B: 49.60	*Practice without GPS*			1st: 3-0 2nd: 1-2	A: 8 B: 8
4	A: 3 B: 3	A: 14 B: 13	A: 38.50 B: 61.50	5.60 ±2.73	27.98 ±11.39	1st: 0.73 9th: 2.44	A: 2 B: 3	A: 5 B: 12	A: 52.71 B: 47.29	5.19 ±2.41	25.96 ±9.01	1st: 0.99 9th: 3.33	1st: 2-1 2nd: 1-1	A: 10 B: 9
5	A: 5 B: 3	A: 15 B: 12	A: 51.50 B: 48.50	6.23 ±2.53	31.49 ±10.48	1st: 0.55 9th: 1.82	A: 5 B: 3	A: 13 B: 10	A: 45.58 B: 54.42	5.15 ±2.54	25.77 ±9.77	1st: 0.98 9th: 3.10	1st: 2-0 2nd: 2-0	A: 9 B: 9
6	A: 2 B: 5	A: 9 B: 9	A: 42.35 B: 57.65	6.46 ±2.45	32.30 ±11.02	1st: 0.70 9th: 1.92	A: 2 B: 8	A: 11 B: 10	A: 62.22 B: 37.78	5.69 ±2.40	28.46 ±8.61	1st: 0.97 9th: 2.67	1st: 0-0 2nd: 0-0	A: 10 B: 8
7	A: 1 B: 5	A: 8 B: 13	A: 50.35 B: 49.65	5.06 ±2.64	23.54 ±10.80	1st: 0.85 9th: 2.33	A: 5 B: 5	A: 11 B: 10	A: 53.69 B: 46.31	4.74 ±2.60	23.69 ±10.61	1st: 1.06 9th: 3.16	1st: 0-1 2nd: 0-0	A: 10 B: 7
8	A: 2 B: 4	A: 17 B: 19	A: 48.94 B: 51.06	4.28 ±2.54	21.42 ±10.29	1st: 1.12 9th: 2.99	A: 3 B: 5	A: 11 B: 10	A: 51.79 B: 48.21	5.90 ±2.45	29.50 ±9.71	1st: 0.72 9th: 1.94	1st: 1-0 2nd: 2-2	A: 7 B: 8
9	A: 4 B: 4	A: 12 B: 14	A: 40.79 B: 59.21	5.99 ±2.42	29.96 ±9.59	1st: 1.03 9th: 2.67	A: 5 B: 3	A: 12 B: 11	A: 46.53 B: 53.47	5.35 ±2.63	26.76 ±10.46	1st: 1.02 9th: 2.98	1st: 0-0 2nd: 0-0	A: 10 B: 10
10	A: 7 B: 4	A: 19 B: 13	A: 49.61 B: 50.39	6.15 ±2.48	30.77 ±9.59	1st: 0.71 9th: 2.25	A: 3 B: 3	A: 8 B: 13	A: 53.40 B: 46.60	6.60 ±2.44	32.98 ±10.46	1st: 0.95 9th: 1.80	1st: 1-0 2nd: 2-1	A: 9 B: 6
11	A: 6 B: 5	A: 9 B: 4	A: 49.21 B: 50.79	5.41 ±2.54	27.04 ±10.11	1st: 0.61 9th: 2.23	A: 6 B: 2	A: 13 B: 10	A: 40.18 B: 59.82	5.94 ±2.53	29.75 ±9.80	1st: 0.80 9th: 2.31	1st: 2-1 2nd: 2-1	A: 9 B: 8
12	A: 5 B: 5	A: 10 B: 13	A: 45.48 B: 54.52	6.10 ±2.40	30.48 ±9.73	1st: 0.67 9th: 2	A: 5 B: 9	A: 15 B: 15	A: 46.54 B: 53.46	4.86 ±2.47	24.32 ±10.37	1st: 0.84 9th: 2.85	1st: 1-0 2nd: 1-1	A: 10 B: 9
13	A: 7 B: 9	A: 12 B: 13	A: 50.59 B: 49.41	6.30 2.55	31.51 ±10.62	1st: 0.56 9th: 2	A: 4 B: 2	A: 9 B: 9	A: 46.16 B: 53.84	5.66 ±2.54	28.32 ±10.27	1st: 0.61 9th: 2.31	1st: 0-3 2nd: 0-0	A: 9 B: 9

Another interesting property found was that all Pc values tended to follow an identical dynamical structure over time. That is, players tended to increase and decrease their number of couplings, simultaneously, highlighting a coordinated search for synchrony and ultimately shaping a similar Tc behaviour. Similar findings were reported by Duarte, Araújo, et al. (2013) that observed near in-phase modes of coordination for player-team synchrony with individual actions being tightly coordinated with team behaviours during players' movements on field.

Mean values of Pc and Tc did not show an increasing trend with practice, as expected. Instead, mean Pc and Tc values oscillated randomly, across weeks, independently of the team formation used and of the players' regularity of participation in teams (see Table 1). This finding opens up the question of how might emergent couplings of players vary in higher-level teams engaged in more regular practices, justifying the need for further studies.

Nonetheless, Rd values of both teams, in general, slightly decreased over weeks, evidencing faster readjustments of coupled players during the rhythmic flow of matches (particularly the Rd value of each player's least coupled teammates). A larger number of couplings seemed also to be associated with faster readjustment movements of players, given that ultrafast regulation of actions is a property of synergies (Riley et al., 2011), here shown to improve with practice.

The tenuous decrease in Rd found for both teams might have been due to the limited amount of practice time that participants experienced. Effects of systematic practice on players of higher skill levels should be further tested. Other possible sources of noise in the data might be due to participants performing other sporting activities outside classes, which could not be controlled; the possibility that some participants had no previous experience in football; and the accumulation of fatigue and lack of conditioning which could have impaired participant tactical performance during tournament matches. Independently, both teams seemed to acquire faster regulating movements after the program. These findings concurred with data reported by Sampaio & Maçãs (2012) who found improvements in coordination tendencies of football teams composed of undergraduate Sports Sciences students enrolled in similar amounts of practice (2 hours per week for 13 weeks). In their study (using 5v5 games), participants displayed more regular oscillating distances to their teams' centres and improved anti-phase patterns in most team dyads, showing that the players' movements became more coordinated with increasing expertise.

Higher frequencies of shots, ball recoveries, goals and percentage of ball possession were not necessarily associated with higher values of Pc and Tc and reduced Rd. Possibly because both teams were receiving the same treatment and thus, equally improving their performance simultaneously. Further studies should be conducted using a control group. However, in the present research only mean values of Pc, Tc and Rd were analysed, thus, the possibility of such match events being associated only with specific periods, where larger numbers of strong synergies are formed should not be excluded. In this sense, it is suggested that future work should try to relate the temporal structure of these variables with the emergence of such match events.

3.5 Conclusions

Moving synchronously on field is a behaviour that most coaches seek to establish in team games. Here we have demonstrated that such team movements are grounded on the formation of synergies, responsible for linking actions of teammates during synchronized rhythmic ebb-and-flow patterns of attack and defence.

In this study, the mean number of couplings established between players and in teams did not show an increasing trend with small amounts of practice. However, players became faster at regulating their movements with teammates by learning to perceive affordances for each other. This occurred with just two hours of practice per week in a sample of undergraduate sports sciences students.

These findings open up new perspectives for the study of coordination processes in sports teams. The emergent couplings supporting synchronised and fast regulating team movements in professional athletes should be further analysed and tested as potential variables to monitor performance improvements over time. The possibility of such variables being reliable predictors of successful team actions should also not be discarded. Future research should aim to match specific performance events (e.g., goals, shots, tackles, etc.) with the dynamic structure of synergy formation.

3.6 References

Almeida, C. H., Ferreira, A. P., & Volossovitch, A. (2014). Effects of Match Location, Match Status and Quality of Opposition on Regaining Possession in UEFA Champions League. *Journal of Human Kinetics, 41*, 203-214.

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*, 653-676.

Bangsbo, J., & Peitersen, B. (2002). *Defensive soccer tactics*. Leeds: Human Kinetics.

Bangsbo, J., & Peitersen, B. (2004). *Offensive soccer tactics*. Champaign, IL: Human Kinetics.

Beek, P., Jacobs, D., Daffertshofer, A., & Huys, R. (2003). Expert performance in sport: Views from the joint perspectives of echological psychology and dynamical systems theory. In J. Starkes & K. A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 321-344). Champaign, IL: Human kinetics.

Bernstein, N. (1967). *The coordination and regulation of movements*. Oxford: Pergamon Press.

Boker, S. M., Xu, M., Rotondo, J. L., & King, K. (2002). Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. *Psychological Methods, 7*(3), 338-355.

Davids, K., Button, C., Araújo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human movement studies. *Adaptive Behavior, 14*, 73-94.

Duarte, R., Araújo, D., Correia, V., Davids, K., Marques, P., & Richardson, M. (2013). Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. *Human Movement Science, 32*, 555-566.

Duarte, R., Travassos, B., Araújo, D., & Richardson, M. (2013). The influence of manipulating the defensive playing method on collective synchrony of football teams. In D. Peters & P. O'Donoghue (Eds.), *Performance Analysis of Sport IX*. London: Routledge, Taylor & Francis Group.

Fajen, B., Riley, M., & Turvey, M. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*, 79-107.

Folgado, H., Duarte, R., Fernandes, O., & Sampaio, J. (2014). Competing with Lower Level Opponents Decreases Intra-Team Movement Synchronization and Time-Motion Demands during Pre-Season Soccer Matches. *PLoS ONE, 9*(5), e97145.

Frencken, W., De Poel, H., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences, 30*(12), 1207-1213.

Frencken, W., Lemmink, K., Delleman, N., & Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science, 11*(4), 215-223.

Gabbett, T., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching, 4*(2), 273-283.

Gibson, J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Hughes, C. (1994). *The football association coaching book of soccer tactics and skills*. Harpenden: Queen Anne Press.

Kelso, J. A. S. (1995). *Dynamic patterns: the self-organizing of brain and behavior*. Massachusetts: MIT Press.

Kelso, J. A. S. (1998). From Bernstein's physiology of activity to coordination dynamics. In M. Latash (Ed.), *Progress in motor control. Bernstein's traditions in movement studies* (pp. 203-219). Champaign, IL: Human Kinetics.

Kelso, J. A. S. (2009). Synergies: Atoms of brain and behavior. In D. Sternad (Ed.), *Progress in motor control: A multidisciplinary perspective* (pp. 83-91). New York: Springer.

Kelso, J. A. S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 367*, 906-918.

Lago, C., Ballesteros, J., Dellal, A., & Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of Sports Science & Medicine, 9*(2), 288-293.

Lago, C., & Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *Journal of Human Kinetics, 25*, 93-100.

Lames, M., Ertmer, J., & Walter, F. (2010). Oscillations in football - order and disorder in spatial interactions between the two teams. *International Journal of Sport Psychology*(41), 85-86.

Latash, M., Scholz, J., & Schöner, G. (2007). Toward a new theory of motor synergies. *Motor Control, 11*, 276-308.

Mark, L. S. (2007). Perceiving the Actions of Other People. *Ecological Psychology, 19*(2), 107-136.

Marsh, K. L., Richardson, M. J., & Baron, R. M. (2006). Contrasting approaches to perceiving and acting with others. *Ecological Psychology, 18*(1), 1-38.

McGarry, T., Anderson, D., Wallace, S., Hughes, M., & Franks, I. (2002). Sport competition as dynamical self-organizing system. *Journal of Sports Sciences, 20*, 771-781.

Palut, Y., & Zanone, P.-G. (2005). A dynamical analysis of tennis: Concepts and data. *Journal of Sports Sciences, 23*(10), 1021-1032.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Riley, M., Shockley, K., & Orden, G. V. (2012). Learning from the body about the mind. *Topics in Cognitive Science, 4*, 21-34.

Sampaio, J., & Maçãs, V. (2012). Measuring tactical behaviour in football. *International Journal of Sports Medicine, 33*(5), 395-401.

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*, 765-772.

Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D., & Garganta, J. (2014). Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams. *PloS One, 9*(9), e107112.

Sinnott, R. W. (1984). Virtues of the Haversine. *Sky and Telescope, 68*(2), 159.

Stoffregen, T., Gorday, K., & Sheng, Y.-Y. (1999). Perceiving affordances for another person's actions. *Journal of Experimental Psychology: Human Perception and Performance, 25*(1), 120-136.

Szwarc, A. (2007). Efficacy of successful and unsuccessful soccer teams taking part in finals of Champions League. *Research Yearbook, 13*(2), 221-225.

Worthington, E. (1974). *Learning and teaching soccer skills*. Hollywood: Wilshire Book Company.

Chapter 4

Effects of Pitch Size and Skill Level on Tactical Behaviours of Association Football Players During Small-Sided and Conditioned Games [7]

PEDRO SILVA, PAULO AGUIAR, RICARDO DUARTE, KEITH DAVIDS, DUARTE ARAÚJO & JÚLIO GARGANTA

Abstract

In association football, the study of variability in players' movement trajectories during performance can provide insights on tactical behaviours. This study aimed to analyse the movement variability present in: (i) the players' actions zones and (ii), in distances travelled over time, considered as a player's positional spatial reference. Additionally, we investigated whether the movement variability characteristics of players from different skill levels varied. Two groups of U-17 yrs players of different performance levels (national and regional) performed in three small-sided games with varying pitch dimensions (small, intermediate and large). Linear and non-linear analyses were used to capture the magnitude and structure of their movement variability. Results showed that increases in pitch size resulted in more restricted action zones and higher distance values from personal spatial positional references for both groups. National players were more sensitive to pitch modifications and displayed more variability than regional players in the small and intermediate pitches. These findings advance understanding about individual tactical behaviours in association football and have implications for training design, using pitch size manipulation.

Keywords: small-sided games; spatial distribution maps; player-to-locus distance; variability; training design.

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[7] Silva, P., Aguiar, P., Duarte, R., Davids, K., Araújo, D., & Garganta, J. (2014). Effects of pitch size and skill level on tactical behaviours of Association Football players during small-sided and conditioned games. *International Journal of Sports Science & Coaching, 9*(5), 993-1006.

4.1 Introduction

In Association Football, analysis and interpretation of individual movement has focused on the players' time-motion characteristics by positional role during competitive match performance or during small-sided and conditioned training games (SSCGs), both receiving a considerable amount of attention (Carling, 2010; Köklü, Ersöz, Alemdaroglu, Asxcxi, & Özkan, 2012; Philippaerts, Cauwelier, Vaeyerns, Bourgois, & Vrijens, 2004). Through this type of analysis, players' physical and physiological profiles have been investigated, providing an important body of knowledge for fitness training. However, strict time-motion analyses provide little information about players' tactical behaviours if they do not consider time-evolving spatial movement trajectories of players during performance.

In human behaviour, variability and nonlinear transitions in movements over time are essential for adaptive flexibility needed under ever-changing constraints of dynamic performance environments (Davids, Glazier, Araújo, & Bartlett, 2003; Hamill, van Emmerik, Heiderscheit, & Li, 1999; Seifert, Button, & Davids, 2013; Stergiou, Harbourne, & Cavanaugh, 2006). A dynamical systems approach proposes the view that coordination variability provides the system with the required flexibility to adapt to perturbations (Hamill, et al., 1999; Harbourne & Stergiou, 2009). From this perspective, movement variability is not viewed as error or noise (Riley, Richardson, Shockley, & Ramenzoni, 2011; Slifkin & Newell, 1999; Slifkin & Newell, 2000), but reflects the adaptability of a performer-environment system usually associated with high levels of skill (Davids, et al., 2003; Harbourne & Stergiou, 2009). It has been shown that a decrease or increase in movement variability can make a neurobiological system more rigid or unstable, respectively, and thus, less adaptable to perturbations (Harbourne & Stergiou, 2009; Seifert, et al., 2013; Stergiou, et al., 2006).

In this context, the study of individual movement variability can explain how individuals performing in complex, dynamic environments, like team games, can manage space and time as a function of specific ecological constraints (Bartlett, Wheat, & Robins, 2007; Davids, Araújo, & Shuttleworth, 2005).

For instance, Fonseca, Milho, Travassos, and Araújo (2012) showed that ball possession impacted on individual movement behaviours in Futsal (indoor football). The attackers' dominant performance regions (constructed from Voronoi cells and representing the specific area allocated to each player in the field) were more variable in size among players of the same team, but displayed more regular sizes than those of defenders, which reflected the performance demands on behaviours of attacking and defending in futsal.

Other studies have recorded the players' predominant action zones (Gréhaigne, 1988; Gréhaigne, Mahut, & Fernandez, 2001) and oscillatory movements around a specific performance locus on field (McGarry, 2005; McGarry, Anderson, Wallace, Hughes, & Franks, 2002) as relevant concepts to quantify individual movements during performance from a tactical perspective. Analysis of movement variability associated with the spatial-temporal characteristics of such concepts may provide important information about individual playing behaviours by reflecting the presence of underlying organisational structures in players' movement patterns. By estimating the variability of players' action zones, one can understand whether play was more or less structured. If players travel through more variable zones on a performance field, it signifies that they are constrained to assume more broad tactical roles (e.g., moving both backwards – defending – and forward – attacking – or on left and right flanks). On the other hand, if players restrict their action zones to specific locations on field, then it can be interpreted as a more structured game, played according to specific positions and roles (e.g., left defender, striker, etc.; see Jones & Drust, 2007).

Movements displayed by a player around a specific geometrical centre, or locus on field, can also provide information on important individual tactical behaviours. The locus represents the player's spatial positional reference around which he/she oscillates (McGarry, 2005). Through the assessment of the variability associated with these oscillatory movements it can be inferred how players manage space and time to converge towards and away from their spatial references during the game. The regularity, to which they are attracted to their locus may be informative about players' awareness of their positional reference on field.

The importance of specific positioning and tactical roles has been considered, for instance, by developmental programmes in junior football, with coaching manuals usually advocating freedom of expression at early ages of practice and evolution into specific positions as players progress from smaller to bigger game formats (FFA, 2012). It has been proposed that small-sided and conditioned games (SSCGs) require players to undertake offensive and defensive roles, while bigger game formats restrict players to specific defending, midfield and attacking positional roles (Jones & Drust, 2007). There exists little firm evidence for this proposal.

Previous research on SSCGs in football, involving pitch size manipulations, has mainly focused on physical and technical characteristics of performance (Kelly & Drust, 2009; Owen, Twist, & Ford, 2004; Tessitore, Meeusen, Piacentini, Demarie, & Capranica, 2006). The only known study in Association Football that addressed performance in SSCGs with varying pitch dimensions *from a tactical perspective* showed that shorter and narrower pitches resulted in smaller longitudinal and lateral inter-team distance values, respectively, whereas a team's surface area decreased as a result of smaller total playing areas (Frencken, van der Plaats, Visscher, & Lemmink, 2013). This study focused the interpersonal relations between players and how they were constrained to adapt their interactive behaviour according to specific pitch size constraints. More studies are needed to understand how pitch size manipulations constrain individual tactical behaviour underlying collective performance in SSCGs. One way to gain this knowledge is through the analysis of the players' movement variability.

Additionally, an understanding of how players' skill levels may influence their adaptation to such constraints could provide valuable information about how individual characteristics impact on performance (Davids, Button, & Bennet, 2008; Phillips, Davids, Renshaw, & Portus, 2010). Many practitioners and performers have been considering stability and consistency in movement, as well as compensatory movement variability to be essential characteristics of skilled performance (Davids, 2001; Handford, 2006; Seifert, et al., 2013). Despite the relevance of spatial-temporal characteristics in football, the extent to which individual movement variability in football SSCGs and/or regular matches is a characteristic of more skilled performers has yet to be demonstrated.

Therefore, the purposes of the present study were twofold. First, we aimed to characterize the individual tactical behaviour of youth football players on SSCGs varying in pitch dimensions, through the analysis of spatial-temporal variability associated to their action zones and movement oscillations around the personal locus. A second aim was to investigate whether the movement variability characteristics of players from different skill levels were varied. We hypothesized that both pitch dimension and skill level would constrain players' movements, with more skilled players presenting higher values of movement variability than their less skilled counterparts across all pitch conditions.

4.2 Methods

4.2.1 Participants

Two clubs participated in this research study, allowing data collection with 10 U-17 youth male football players (N=20). The skill level was set based on competitive performance level. Players from Club A (aged 16.20±0.63 years old) competed at a national-level. Players from Club B (aged 15.60±0.52 years old) competed in the 2^{nd} division of their district competition. Based on these criteria, participants were classified at national-level (NLP) or regional-level (RLP) of performance. All participants possessed more than six years of playing experience at their respective levels (NLP: 6.6±1.65 years; RLP: 6.2±2.35).

4.2.2 Experimental design

Each group of players was assigned to two teams by their respective coaches to ensure a balanced competitive game. Each team was composed of one goalkeeper, one defender, two midfielders and one striker, all of them specializing in these performance roles for more than three years.

Both groups performed in three SSCGs of 7 minutes duration interspersed with 7 minutes resting periods to minimize the influence of fatigue on participants (exercise-rest ratio of 1:1)[8].

The SSCGs consisted of games of 4-a-side plus goalkeepers using 7-a-side goals. The goalkeepers played inside an area marked five-meters from the goal line and extending across the pitch width. Passing the ball to the goalkeeper was not allowed. All SSCGs were played accordingly to the remaining official rules of Association Football with the exception of the offside rule that was not applied.

During the SSCGs and rest periods, coaches did not provide any instructions, feedback or encouragement to the players. Several balls were placed around the pitches so that players could restart matches quickly when balls left the field of play. During recovery periods, participants were allowed to recover actively at will through low intensity activities. Common activities involved stretching, playing short passes between pairs and rehydration.

Pitch dimensions were calculated using the measures of an official football field – 105 x 68 m as a reference. The length and width were then reduced in proportion to the number of players involved in the SSCGs, as suggested in coaching literature (Hughes, 1994). The percentage of players involved in each SSCG was 45% (10 out of 22 players), and 45% of the official length and width corresponded to the intermediate pitch length and width. For small and large pitches, 10% was subtracted and added to the initial value of 45%, respectively (Table 2). The same ratio of 1.5:1 was maintained between length and width in all three pitches.

Both groups of participants played in the smallest pitch first, then the intermediate and ended with the largest pitch. The order of the SSCGs was set arbitrarily.

This protocol was operationalized prior to the clubs' regular training sessions (both teams used to practice in the late afternoon) in the middle of the week (i.e., equally distant from the last and the next official team competitive fixture). The players were informed that

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[8] All players wore vests that contained heart rate monitors. The Edwards' training load (ETL) and the total distance travelled (TDT) per player were calculated to analyse any possible effects of fatigue on the experimental outcomes. As expected, the training load analysis yielded a greater physiological impact in the RLP in all SSCGs, albeit without significant differences between groups ($p=0.820$, $\eta^2=0.01$). There was also a considerable difference between NLP and RLP in the TDT per player in each pitch condition ($p<0.001$, $\eta^2=0.58$), with the greatest difference being noted on the large pitch, where the RLP have covered, on average, over 100 meters more than the NLP. It is unlikely that the less skilled players could have had a greater physiological impact on the last SSCG bout and yet still ran for greater distances than participants in the skilled group. In this sense, it seems that this outcome was due to tactical adaptations of each group to the specific task constraints and not due to fatigue.

they would not participate in that day's training session after the completion of the experiment.

All players were familiarized with the practice of different SSCGs formats experienced since they had begun to play football.

Table 2 – Pitch dimensions. Percentages represent the proportion of official width and length measures (105 x 68 m).

	Small pitch (35%)	**Intermediate pitch (45%)**	**Large pitch (55%)**
Width	23.8 m	30.6 m	37.4 m
Length	36.8 m	47.3 m	57.8 m
Individual playing area	≈ 88 m^2	≈ 145 m^2	≈ 216 m^2

4.2.3 Data Collection

Each player carried a global positioning tracking device (SPI Pro, GPSports, Canberra, Australia) that recorded longitudinal and latitudinal movement coordinates with a sampling frequency rate of 15Hz.

All pitches were calibrated with the coordinates of four GPS devices that were stationed in each corner of the pitch for about 2 minutes. The absolute coordinates of each corner were calculated as the median of the recorded time series, providing measurements that were robust to the typical fluctuations of the GPS signals. These absolute positions were used to set the Cartesian coordinate systems for each pitch, with the origin placed at the pitch centre. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). Fluctuations in the players' positions were reduced using a moving average filter with a time scale of 0.2 seconds and data resampling was employed to synchronize the time series of all players within each game.

4.2.4 Data analysis

In this study, linear and non-linear analyses were used to examine the variability of the players' spatial-temporal characteristics. Linear tools used involved the percentage of coefficient of variation (CV) to quantify the overall variability. CV was complemented with non-linear methods that are paramount to describe the structure of variability (Harbourne & Stergiou, 2009; Pukėnas, Poderys, & Gulbinas, 2012). It involved two specific measures of entropy – Shannon and sample entropies.

Therefore, Shannon entropy measures (Shannon, 1948) of individual spatial distribution maps were used to assess the underlying variability of the players' spatial distribution, providing a value that quantifies the uncertainty of locating each player in a specific location of the pitch (goalkeepers excluded). To calculate the spatial distribution maps, the pitch was discretized into bins and the amount of time spent in each bin was measured, according to the sampling frequency of the GPS acquisition system. The spatial distribution maps were normalized to total match time, to produce spatial probability distributions (2D). The size of the bins was the same for all pitches, chosen to satisfy an adequate balance between high spatial resolution and high range of measured values. A bin size of 1m^2 was used allowing both sufficient spatial detail and large variability in the bin counting (>100×dt).

Considering a pitch partition with *N* bins and setting p_i as the measured probability of finding the player in bin *i*, the entropy *S* of the spatial distribution is:

$$S = -\sum_{i=1}^{N} p_i \log p_i \qquad (1)$$

Normalized entropy was used to place the results within the range between 0 and 1:

$$S\% = \frac{1}{\log N} \sum_{i=1}^{N} p_i \log p_i \qquad (2)$$

A low Shannon entropy (ShannEn) value (near 0) indicates that the distribution is sharply peaked and the player's position can be easily predicted. A high ShannEn value (near 1) indicates that the distribution is uniform and thus, the player's position is highly variable and unpredictable. High and low ShannEn values were interpreted as high and low spatial distribution variability, respectively.

To analyse the time-evolving structure of the players' movement variability, an individual locus was assigned to each player and the instantaneous distances to this locus were calculated for each time point. The locus was defined as the median point (2D) of their motion trajectory due to the non-parametric distribution of data. The distance to the locus (L) time series was computed for each player (P) using the Pythagoras theorem:

$$D_{(L,P)}=\sqrt{}((Lx - Px) + (Ly - Py))^2 \qquad (3)$$

Linear analyses of the time series were performed to analyse the *magnitude* of the variability using the mean (M), standard deviation (SD) and percentage of coefficient of variation (CV) parameters.

Non-linear analyses were used to assess the *structure* of the variability of the signals using sample entropy measures (SampEn). SampEn(*m, r, N*) is defined as the negative natural logarithm of the conditional probability that two sequences similar for *m* points (length of the vector to be compared) remain similar at the next point *m + 1* (Richman & Moorman, 2000). The similarity criterion is set by *r*×SD of the time-series. The parameter combination used in this study was m = 3 and r = 0.1 (see appendix for details on parameters choice).

All player-to-locus distances (PLdt) time series were down-sampled to avoid local stationarities in SampEn calculation, which can ultimately lead to a decrease in entropy due to an increase in the number of matches of the template pattern (Rhea et al., 2011). Median PLdt velocity and acceleration for all sixteen players in all pitches were below 1m/s and 1m/s^2, respectively. Therefore, a sampling rate of 1Hz was considered reasonable to capture PLdt time-variations under any pitch and skill conditions (N=420 data points, each point corresponding to 1-s).

SampEn values range from 0 towards infinity, where 0 represents a perfectly repeatable time series and infinity is a totally unpredictable time series. From this measure it can be inferred whether players displayed highly regular (i.e, periodical) (low SampEn) or highly irregular (high SampEn) PLdt.

Both spatial distribution maps and PLdt time series were calculated using MATLAB routines (R2011a, Mathworks, USA).

4.2.5 Statistical procedures

ShannEn, PLdt, CV and SampEn were subjected to a mixed design split-plot ANOVA with a repeated measures (RM) design for pitch dimensions (3) and a between-groups effect for skill level (2). Effect sizes were reported as partial eta squared (η^2) and significant results were followed up with Bonferroni's pairwise comparisons. Greenhouse-Geisser adjustments were applied to violations of the sphericity assumption for the RM variable. The value of α was set at p=0.05.

All statistical analyses were conducted in SPSS 20.0 (SPSS Inc., Chicago, USA).

4.3 Results

4.3.1 Spatial distribution variability

In both groups, ShannEn values decreased as pitch dimension increased (Figure 6, top left panel). ANOVAs yielded a main effect for pitch dimension ($F=37.57$, $p<0.001$, $\eta^2=0.73$) and an interaction effect between pitch dimension and skill level ($F=6.99$, $p=0.003$, $\eta^2=0.33$).

Post-hoc analysis revealed significant differences between all pitches for the NLP ($p<0.001$ in all comparisons). The RLP presented significant differences between the small and the intermediate pitches ($p=0.002$), but not between the intermediate and the large pitches ($p=0.71$). Also, significant differences in ShannEn values were observed between NLP and RLP according to pitch dimensions. The NLP presented significantly higher values of ShannEn on small and intermediate pitches ($p=0.01$ and $p=0.004$, respectively), but not on the large pitch ($p=0.59$).

Figure 7 presents exemplar spatial distribution maps of two players from each group for each pitch dimension, highlighting higher variability in spatial distributions for the national-level players on the small and intermediate pitches.

4.3.2 Player-to-locus distance variability

Exemplar player-to-locus distance (PLdt) time-series of the same players are plotted in Figure 8. Both groups exhibited a sinusoidal signal type, describing near-cyclical movements towards and away from the locus in a relatively periodical fashion.

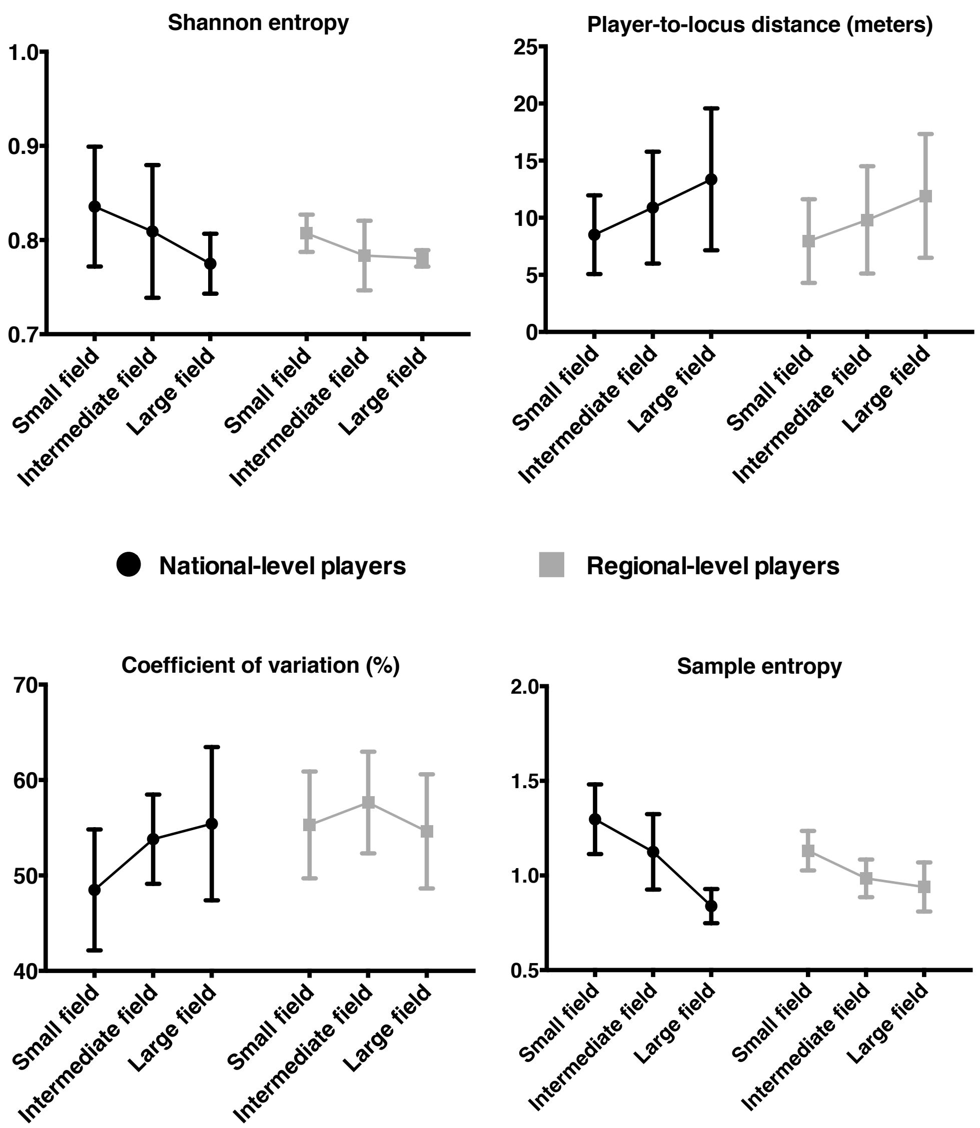

Figure 6 - Shannon entropy (top left panel), player-to-locus distance (top right panel), coefficient of variation (bottom left panel) and sample entropy (bottom right panel) mean values. Error bars represent standard deviation.

In both groups, PLdt increased with pitch dimensions (Figure 6, top right panel). A main effect was observed for PLdt by pitch dimensions (F=79.161, $p<0.001$, $\eta^2=0.85$), but no interaction effects between pitch dimension and skill level were found (F=0.82, p=0.41, $\eta^2=0.06$). Post-hoc testing revealed that both groups significantly increased their PLdt across pitches ($p<0.05$ for all comparisons). Significant differences between groups according to pitch were only reported on the intermediate pitch (p=0.04).

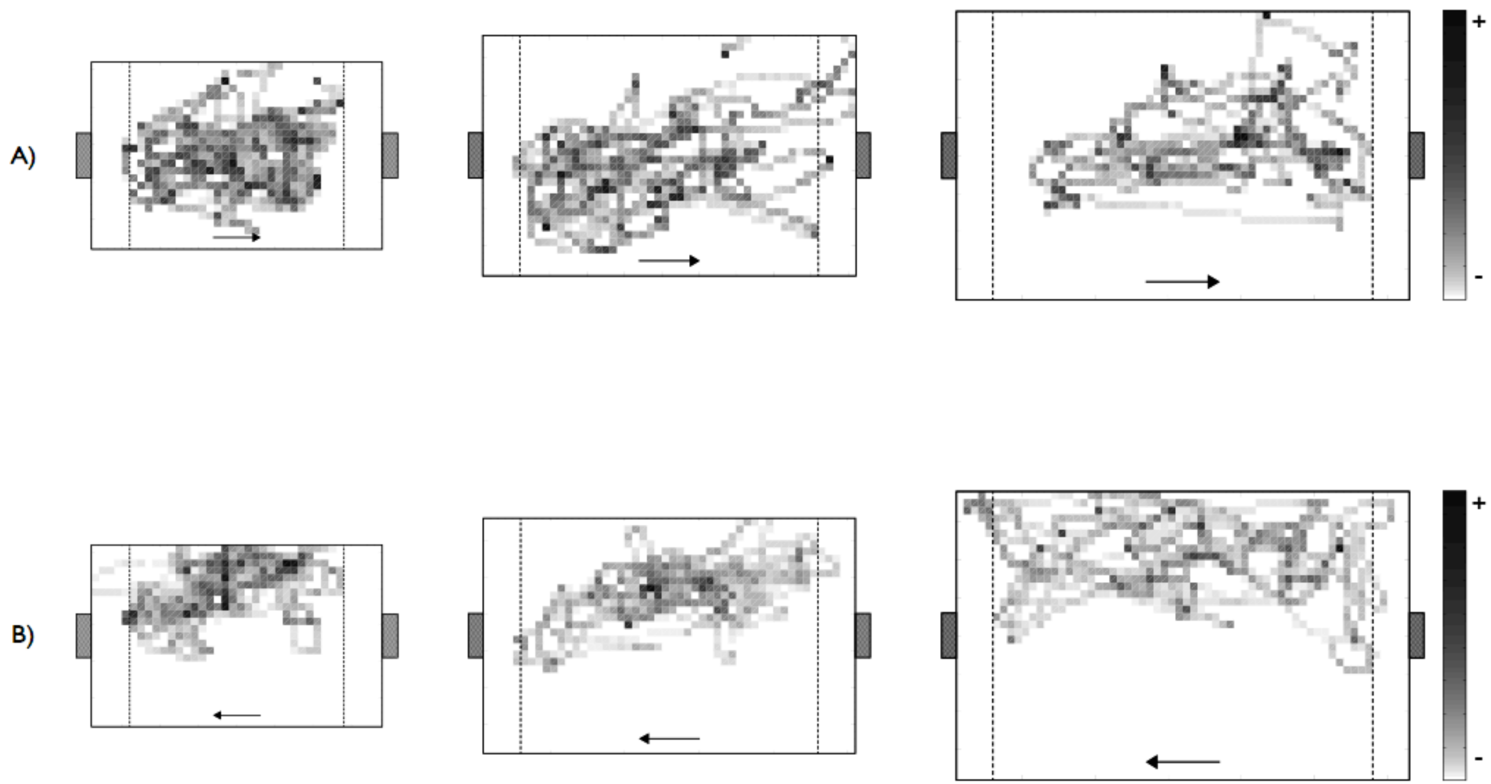

Figure 7 - Exemplar spatial distribution maps of two players from each group - A) national-level player; B) regional-level player. Both players usually performed as midfielders in competitive matches. Arrows represent attacking direction. The national-level player presents more variability in bin occupation in relation to the RLP in the small and intermediate pitches.

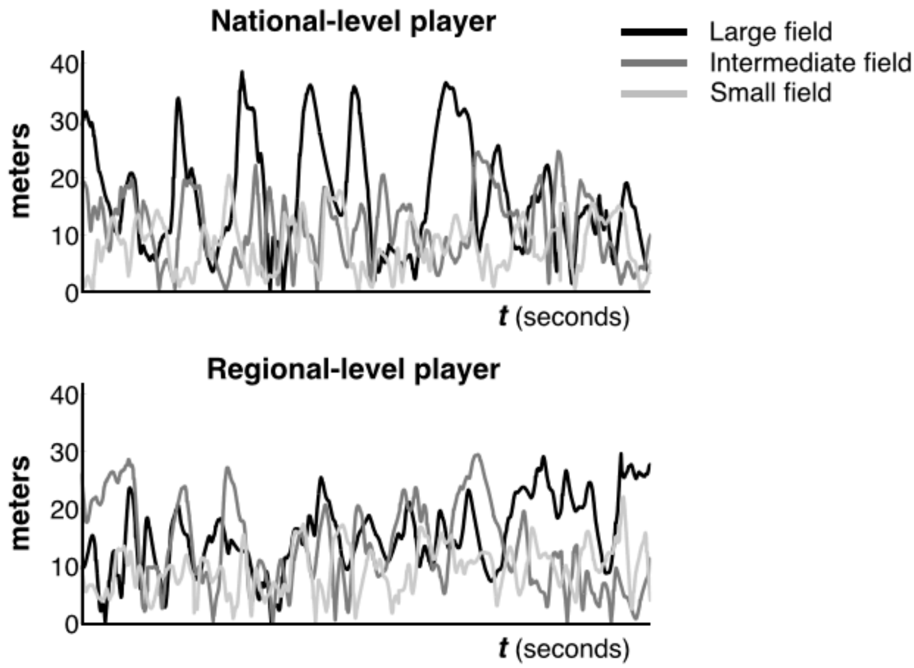

Figure 8 - Exemplar player-to-locus distance time-series (7 minutes) of the same midfield players presented in Fig. 2. Upper panel: national-level player; lower panel: regional-level player. Both exhibit a near-sinusoidal cyclical pattern in all pitches.

Coefficient of variation values increased across pitches for NLP, while RLP presented higher levels in the intermediate pitch and lower levels in the small and large pitches (Figure 6, bottom left panel). No main effects were observed for CV by pitch dimension (F=2.69, p=0.08, η^2=0.16). There were, no interaction effects between pitch dimension and skill level (F=2.38, p=0.11, η^2=0.15).

NLP presented significant differences in CV values between the small and the intermediate pitch (p=0.02) and between the small and large pitch (p=0.01). The RLP did not show significant differences between any of the pitch dimensions for CV. Groups differed significantly only on the small pitch (p=0.04) with RLP presenting higher levels of CV.

Concerning the regularity of PLdt, SampEn values decreased across pitches for both groups (Figure 6, bottom right panel). Significant main effects were found for pitch dimension (F=21.472, p<0.001, η^2=0.605) and interaction effects were found between pitch dimension and skill level (F=5.795, p=0.008, η^2=0.293). Post-hoc tests for SampEn did not reveal significant differences between groups in any of the pitches. However, p-values close to a borderline level of significance were found in the small (p=0.076), intermediate (p=0.087) and large pitches (p=0.064), with higher SampEn mean values being displayed in the small and intermediate pitches for the NLP, and in the large pitch for the RLP. The NLP have significantly decreased their SampEn values across pitches ($p<0.05$ for all comparisons) but the RLP have only reported significant differences between the small and the intermediate pitch (p=0.050, a borderline value) and between the small and the large pitch (p=0.004). This same group (RLP) did not present a significant decrease in SampEn between the intermediate and the large pitch (p=0.836).

4.4 Discussion

This study examined the individual movement variability of young football players during SSCGs as a function of skill level and pitch dimension.

To assess the players' behaviours, linear and non-linear tools were used to analyse the variability of the players' action zones and of their movements toward and away from a personal locus of reference around which actions were developed throughout the performance. These measures provided information about the spatial distribution and movement displacement characteristics such as magnitude of variation and regularity.

4.4.1 Spatial distribution variability

As pitch size increased, we found more restricted action zones for players of both groups (NLP and RLP). On small and intermediate pitches, players presented more variable action zones, which revealed more uncertainty in their behavioural modes. These data suggested that play was more structured on the large pitch, with players self-organising into specific roles and positions to ensure a balanced occupation of the playing field. Smaller pitches required the players to explore more variable areas of the pitch. This is probably due to greater proximity to opposing players, which limits the available space and time to play (Frencken, et al., 2013). In this context, attacking players needed to move more and explore variable zones in the pitch in order to create free space, while defenders tried to decrease time, space for attacking players (Bangsbo & Peitersen, 2002; Hughes, 1994; Mitchell, 1996).

The NLP group presented larger differences in their spatial distributions across pitches than the RLP group, as indicated by effect size values. The former seemed to be more sensitive to modifications in the available area of play and adapted their behaviours accordingly through increased performance regularity as pitch size increased. Despite having decreased their performance variability across pitches, the RLP did not present significant differences between any of the pitches, denoting less sensitivity to specific playing areas.

The NLP group also presented significantly higher variability on the small and intermediate pitches than their less skilled counterparts, but not on the large pitch as hypothesized. Analysis of individual RLPs spatial distribution maps showed that, even on smaller pitches, preferred action zones were identified for some players. On the other-hand, the NLP's spatial distribution maps only identified a predominant action zone on the large pitch (central corridor) while presenting high variable action zones in the small and intermediate pitches. These results clearly showed that players of different skills respond differently to the same task constraints. A possible explanation may be that in smaller pitches, more tackles, shots, challenges, loss of ball possessions and physical contact may occur (Dellal et al., 2012; Kelly & Drust, 2009). These game events are deemed perturbations that change the rhythmic flow of attacking and defending (Hughes, Dawkins, David, & Mills, 1998; McGarry, et al., 2002). Therefore, the higher spatial variability presented by NLP may reflect their superior ability in coping with perturbations to stabilize a desired tactical playing configuration to adapt to the SSCGs constraints.

The higher spatial variability of NLP in the small and intermediate pitches may have also been influenced by the different movement preferences of the players, resulting from possessing a higher skill level than RLP. More skilful players adapt better to restricted spaces, whereas less skilful players need larger spaces (Wade, 1978). Skill is considered to have a major influence on a player's repertoire of possible game play decisions (Gréhaigne, Richard, & Griffin, 2005), including where to move.

4.4.2 Player-to-locus distance variability

Results showed that increases in pitch dimensions constrained the players to move further away from their locus. The movements toward and away from the locus were exhibited in both groups within a near cyclical sinusoidal pattern, reflecting the players' tendency to travel around a preferred reference zone during the rhythmic ebb-and-flow of attacking and defending. Despite having presented slightly higher values of PLdt (with significant differences between groups reported only for the intermediate pitch), NLP were more consistent in such distances, by presenting lower percentages of CV in the small and intermediate pitches. Interestingly, despite having shown PLdt measures similar to the NLP, as well as less variable spatial distributions on the small pitch, the RLP also presented less consistent distances to their locus when compared with NLP. In contrast, skilled players searched for and moved to more variable areas of the pitch to cope with the constraints imposed by smaller spaces, while maintaining, at the same time, higher consistency in the distances to their positional locus. This finding might reflect higher perceptiveness of effective space management during performance. Further evaluations of these characteristics need to occur in future studies in order to investigate the advantages of presenting such tactical patterns.

With regards to displacement regularity, both groups of players presented less complex and variable behaviours as pitch size increased. The decrease in SampEn values indicated more regularity in players' displacements around their locus as the space of play became larger. As with spatial variability, the NLP presented a heavy tendency to displace more regularly across pitches when compared to RLP. This, again, suggests a higher degree of sensitiveness to modifications in task constraints.

In the small and intermediate pitches, despite having presented higher consistency in their PLdt, NLP were more irregular on their movements toward and away from the locus. As previously mentioned, they also presented significantly more spatial variability in these pitches. Again, we speculate that higher PLdt variability presented by NLP in the small and intermediate pitches represents optimal variability reflecting superior ability to adapt to the specific constraints imposed during SSCGs practices. Higher unpredictability in movement behaviour may favour the tactical playing patterns required to cope with the available space and time to play and the higher number of perturbations in smaller pitches. Curiously, in the large pitch, NLP displayed slightly higher PLdt values and slightly higher displacements regularity when compared to RLP. Previously, we have reported also their lower spatial variability in this pitch condition. This means that despite having distanced themselves further from their zone of reference, they were still more regular in the zones visited and in their rhythmical movements. This may evidence superior tactical awareness of their playing roles and positional play in larger spaces.

Contrary to our expectations, NLP presented higher regularity than RLP in the large pitch. It is not known how the players can benefit from lower variability levels in the large pitch. In previous research comparing participants of different expertise bouncing a ball it was also found that movement variability increased and decreased as a function of skill and the task being performed (Broderick & Newell, 1999). In this case, the decrease in variability may be associated with the positional behaviours adopted in the large pitch. In this SSCG, players performed a more structured play by fixing their positions into more restricted action zones. The extent to which this strategy benefits from low individual movement variability shall be investigated in the future.

4.5 Conclusion

The findings of this study confirm that both pitch dimension and the players' skill have an influence on their movement variability. Their action zones became more restricted as available playing area increased, suggesting a more structured style of play, according to specific positioning and playing roles (e.g., attacker, defender, right wing, left wing). Players also tended to move more regularly (i.e., periodically) around their positional spatial reference (i.e., the locus). As expected, the most skilled players were more sensitive to pitch size manipulations and presented both higher marked differences across pitches, and significant higher variability in the small and intermediate pitches, meaning that the same task constraints can yield different effects according to the players' competitive standard.

While higher variability in individual movement behaviour may be interpreted as the necessary unpredictability to cope with the reduced time and space available to play in smaller pitches, it is not known how players can benefit from lower movement variability in larger spaces. It seems to exist an association with the degree of structured play and lower levels of variability. In this sense, we suggest future studies to investigate if decreases in individual movement variability are associated with behavioural changes at a team level and vice-versa. Another clarification that is needed in the future is about the functionality of the variability that is reduced. Perhaps skilled players reduce mainly non-functional variability (Latash, Scholz, & Schoner, 2002).

The findings of this study may be limited in extent by the sample size and by the sequence of SSCGs used in the experimental setting. It is proposed that future investigations attempt to evaluate a higher number of participants using different research designs.

4.6 Practical Applications

In this study, there are implicit some important messages for practitioners. When designing SSCGs, it should be considered that smaller pitches seem to rehearse game situations resulting in higher unpredictable action zones and less attraction towards the players' spatial positional references, whereas larger spaces seem to appeal to a more structured playing style and more attraction towards spatial positional references. Thus, pitch size manipulations can be used to shape the players' tactical behaviours according to stricter or broader tactical roles. The skill level of the practitioners shall also be accounted since different individual capabilities may result in different tactical adaptations to the SSCG requirements.

4.7 Appendix

AR models of various orders (1 to 10) were fit to the data with the argument that if data come from an AR(*p*) process then $m \geq p$. Thus, *m* can be estimated by solving the first *p* Yule-Walker equations with correlations estimated using the sample autocorrelation coefficients. The order of the process is, then, estimated to minimize the Schwarz's Bayesian criterion that represents a trade-off between the fit of the AR model and the number of parameters estimated (Chatfield, 2003). Results yielded 90% of the estimates provided with the AR processes to be between 2 and 5 (Figure 9). Based on this finding, we have used *m* values ranging from 2 to 5.

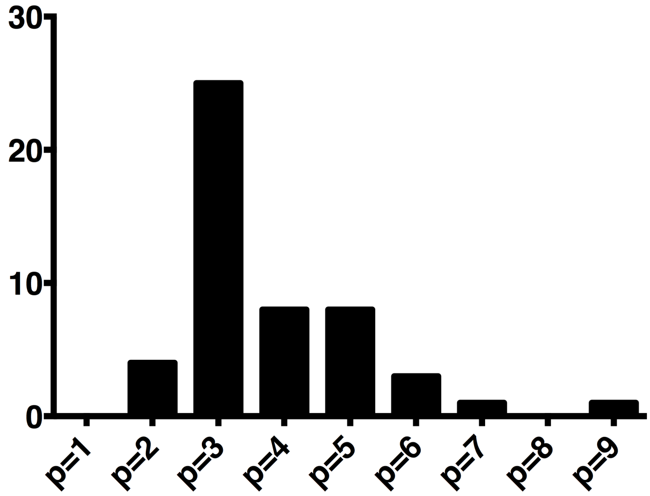

Figure 9 - Number of estimates provided with each of the AR model orders.

The *r* parameter to be picked shall minimize the efficiency metric $Q = \{\max \sigma CP/CP,\ \sigma CP/\text{-}\log(CP).CP\}$, which represents the maximum relative error of SampEn and of the conditional probability estimate (CP), respectively. This criterion reflects the efficiency of the entropy estimate because it favours estimates with low variance and simultaneously penalizes CP near 0 and near 1. Thus, for each player time series, it was calculated

SampEn and CP relative errors for the range values of m={2, 3, 4, 5} and r=0.1 to 0.8 in steps of 0.1. The players' median values of Q for each (m, r) combination ranged from 0.405 to 0.951. For our data we have selected m=3 and r=0.1 because: (i) m = 3 is acceptable because of the AR analysis and (ii) r = 0.1 is the value that better fits m = 3 since it minimizes the quantity Q (for m = 3 and r = 0.1, Q = 0.405, which is the lowest value of the efficiency metric).

For more detailed justifications on these procedures see Lake, Richman, Griffin, & Moorman (2002), page R791.

4.8 References

Bangsbo, J., & Peitersen, B. (2002). *Defensive soccer tactics*. Leeds: Human Kinetics.

Bartlett, R., Wheat, J., & Robins, M. (2007). Is movement variability important for sports biomechanists? *Sports Biomechanics, 6*(2), 224-243.

Broderick, M. P., & Newell, K. M. (1999). Coordination patterns in ball bouncing as a function of skill. *Journal of Motor Behavior, 31*(2), 165-188.

Carling, C. (2010). Analysis of physical activity profiles when running with the ball in a professional soccer team. *Journal of Sports Sciences, 28*(3), 319-326.

Chatfield, C. (2003). *The analysis of time series: an introduction.* (Sixth ed.). New York: Chapman & Hall.

Davids, K. (2001). Genes, training, and other constraints on individual performance: a role for dynamical systems theory? *Sportscience, 5*(2). Retrieved from sportsci.org/jour/0102/kd.htm

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of dynamical system theory to Football. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science & Football V* (pp. 556-569). Oxon: Routledge.

Davids, K., Button, C., & Bennet, S. (2008). *Dynamics of skill acquisition: a constraints-led approach.* Champaign (IL): Human kinetics.

Davids, K., Glazier, P., Araújo, D., & Bartlett, R. (2003). Movement systems as dynamical systems: the functional role of variability and its implications for Sports Medicine. *Sports Medicine, 33*(4), 245-260.

Dellal, A., Owen, A., Wong, D. P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science, 31*(4), 957-969.

FFA. (2012). *Optus small sided football handbook*: Football Federation Australia.

Fonseca, S., Milho, J., Travassos, B., & Araújo, D. (2012). Spatial dynamics of team sports exposed by Voronoi diagrams. *Human Movement Science, 31*(6), 1652-1659.

Frencken, W., van der Plaats, J., Visscher, C., & Lemmink, K. (2013). Size matters: Pitch dimensions constrain interactive team behaviour in soccer. *Journal of Systems Science and Complexity, 26*(1), 85-93.

Gréhaigne, J.-F. (1988). Game systems in soccer from the point of view of coverage of space. In T. Reilly, A. Lees, K. Davids & W. J. Murphy (Eds.), *Science and Football* (pp. 316-321). London: E. & FN Spon.

Gréhaigne, J.-F., Mahut, B., & Fernandez, A. (2001). Qualitative observation tools to analyse soccer. *International Journal of Performance Analysis in Sport, 1*, 52-61.

Gréhaigne, J.-F., Richard, J. F., & Griffin, L. (2005). *Teaching and learning team sports and games*. Oxon: Routledge (Taylor & Francis Group).

Hamill, J., van Emmerik, R. E. A., Heiderscheit, B. C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics, 14*(5), 297-308.

Handford, C. (2006). Serving up variability and stability. In K. Davids, S. Bennett & K. Newell (Eds.), *Movement system variability* (pp. 73-83). Champaign, IL: Human Kinetics.

Harbourne, R. T., & Stergiou, N. (2009). Movement variability and the use of nonlinear tools: principles to guide physical therapist practice. *Physical Therapy, 89*(3), 267-282.

Hughes, C. (1994). *The football association coaching book of soccer tactics and skills*. Harpenden: Queen Anne Press.

Hughes, M., Dawkins, N., David, R., & Mills, J. (1998). The perturbation effect and goal opportunities in soccer. *Journal of Sports Sciences, 16*(20), 20.

Jones, S., & Drust, B. (2007). Physiological and technical demands of 4v4 and 8v8 games in elite youth soccer players. *Kinesiology, 39*(2), 150-156.

Kelly, D., & Drust, B. (2009). The effect of pitch dimensions on heart rate responses and technical demands of small-sided soccer games in elite players. *Journal of Science and Medicine in Sport, 12*(4), 475-479.

Köklü, Y., Ersöz, G., Alemdaroglu, U., Asxcxi, A., & Özkan, A. (2012). Physiological responses and time-motion characteristics of 4-A-side small-sided game in young soccer players: The influence of different team formation methods. *Journal of Strength and Conditioning Research, 26*(11), 3118-3123.

Lake, D., Richman, J., Griffin, P., & Moorman, R. (2002). Sample entropy analysis of neonatal heart rate variability. *American Journal of Physiology: Regulatory, Integrative and Comparative Physiology, 283*, R789-R797.

Latash, M. L., Scholz, J. P., & Schoner, G. (2002). Motor control strategies revealed in the structure of motor variability. *Exercise and Sport Sciences Reviews, 30*, 26-31.

McGarry, T. (2005). Soccer as a dynamical system: some theoretical considerations. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science & Football V* (pp. 570-579). Oxon: Routledge.

McGarry, T., Anderson, D., Wallace, S., Hughes, M., & Franks, I. (2002). Sport competition as dynamical self-organizing system. *Journal of Sports Sciences, 20*, 771-781.

Mitchell, S. A. (1996). Improving invasion game performance. *JOPERD: The Journal of Physical Education, Recreation & Dance, 67*(2), 30-33.

Owen, A., Twist, C., & Ford, P. (2004). Small-sided games: The physiological and technical effect of altering pitch size and player numbers. *Insight, 7*(2), 50-53.

Philippaerts, R., Cauwelier, D., Vaeyerns, R., Bourgois, J., & Vrijens, J. (2004). Anthropometric characteristics, physical fitness and technical ability according to positional role and level in youth soccer *Journal of Sports Sciences, 22*(6), 557-557.

Phillips, E., Davids, K., Renshaw, I., & Portus, M. (2010). Expert performance in sport and the dynamics of talent development. [Editorial]. *Sports Med, 40*(4), 271-283.

Pukėnas, K., Poderys, J., & Gulbinas, R. (2012). Measuring the complexity of a physiological time series: a review. *Education. Physical Training. Sport*(84), 48-54.

Rhea, C. K., Silver, T. A., Hong, S. L., Ryu, J. H., Studenka, B. E., Hughes, C. M. L., et al. (2011). Noise and Complexity in Human Postural Control: Interpreting the Different Estimations of Entropy. *PLoS ONE, 6*(3), e17696.

Richman, J., & Moorman, R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *Am J Physiol Heart Circ Physiol, 278*, H2039-H2049.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Seifert, L., Button, C., & Davids, K. (2013). Key Properties of Expert Movement Systems in Sport. *Sports Medicine, 43*(3), 167-178.

Shannon, C. (1948). A mathematical theory of communication. *The Bell System Technical Journal, 27*(3), 379-423.

Sinnott, R. W. (1984). Virtues of the Haversine. *Sky and Telescope, 68*(2), 159.

Slifkin, A., & Newell, K. M. (1999). Noise, information transmission, and force variability. [Article]. *Journal of Experimental Psychology-Human Perception and Performance, 25*(3), 837-851.

Slifkin, A., & Newell, K. M. (2000). Variability and Noise in Continuous Force Production. *Journal of Motor Behavior, 32*(2), 141.

Stergiou, N., Harbourne, R. T., & Cavanaugh, J. T. (2006). Optimal Movement Variability: A New Theoretical Perspective for Neurologic Physical Therapy. *Journal of Neurologic Physical Therapy, 30*(3), 120-129.

Tessitore, A., Meeusen, R., Piacentini, M. F., Demarie, S., & Capranica, L. (2006). Physiological and technical aspects of "6-a-side" soccer drills. *Journal of Sports Medicine and Physical Fitness, 46*(1), 36-43.

Wade, A. (1978). *The FA guide to teaching football*. London: William Heinemann Ltd.

Chapter 5

Field Dimension and Skill Level Constrain Team Tactical Behaviours in Small-Sided and Conditioned Games in Football [9]

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Abstract

This study analysed the influence of field dimension and players' skill level on collective tactical behaviours during small-sided and conditioned games (SSCGs). Positioning and displacement data were collected using global positioning systems (15 Hz) during SSCGs (Gk+4 v. 4+Gk) played by two groups of participants (NLP- national-level and RLP regional-level players) on different field dimensions (small: 36.8 x 23.8 m; intermediate: 47.3 x 30.6 and large: 57.8 x 37.4 m). Team tactical performance was assessed through established dynamic team variables (effective playing space, playing length per width ratio and team separateness) and non-linear signal processing techniques (sample entropy of distances to nearest opponents and the teams centroids' mutual information). Results showed that the effective playing space and team separateness increased significantly with pitch size regardless of participant skill level ($p<0.001$, $\eta^2=0.78$ and $p<0.001$, $\eta^2=0.65$, respectively). Playing length per width ratio increased with pitch size for the NLP but was maintained at a relatively constant level by RLP across treatments indicating different playing shapes. There was significantly more irregularity in distances to nearest opponents for the NLP in small ($p=0.003$) and intermediate fields ($p=0.01$). Findings suggest that tactical behaviours in SSCGs are constrained by field size and skill level, which need to be considered by coaches when designing training practices.

Keywords: collective behaviours; task constraints; small-sided games.

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[9] Silva, P., Duarte, R., Sampaio, J., Aguiar, J., Davids, K., Araújo, D. & Garganta, J. (2014). Field dimension and skill level constrain team tactical behaviours in small-sided and conditioned games in football. *Journal of Sports Sciences,* 32(20), 1888-1896.

5.1 Introduction

Sports teams have been modelled as interacting social units which benefit from natural processes of self-organization among players who cooperate with each other to achieve common intended goals (Duarte, Araújo, Correia, & Davids, 2012; Silva, Garganta, Araújo, Davids, & Aguiar, 2013). This conceptualisation has several implications for training design in team sports, since manipulation of specific key task constraints may channel individual and team tactical behaviours into stable and functional coordination patterns (or attractors) during goal-directed team activities (Araújo, Davids, Bennett, Button, & Chapman, 2004; Handford, Davids, Bennett, & Button, 1997).

In association football, the use of small-sided and conditioned games (SSCGs) constitutes an example of goal-directed team training activities widely used by coaches to shape technical, physical and tactical skills, concurrently (Davids, Araújo, Correia, & Vilar, 2013; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011). At present, the acute physiological and technical responses under different SSCGs constraints have been extensively addressed in the literature (see Hill-Haas et al., 2011, for a review). For example, previous studies showed that enlarging field dimensions increased the physical and physiological workload and the rating of perceived exertion of male youth football players (Casamichana & Castellano, 2010), while smaller pitches promoted a higher number of shots, tackles, challenges, loss of ball possessions and physical contact incidents (Dellal et al., 2012; Kelly & Drust, 2009). However, interpersonal coordination patterns that may emerge from the individual and team tactical behaviours performed during such tasks have scarcely been studied.

In fact, field dimension is one of the most frequently manipulated constraints in SSCGs during team games practice and yet little is known about the outcomes of these changes. By altering the available space to play, the areas covered by players of both teams, and their relationships, trajectories and distances on field, may change due to changing informational constraints like ball trajectory, location of the goal and nearest defenders. Previous research has shown how such informational constraints can afford specific technical actions like shooting (Vilar, Araújo, Davids, Correia, & Esteves, 2012), dribbling (Duarte, Araújo, Davids, et al., 2012; Duarte et al., 2010) and passing (Travassos et al., 2012).

On what concerns tactical performance, experiential knowledge of high level coaches supports the assumption that games played in smaller playing areas reduce the distances between opponent players, whereas creation of space may be more easily achieved using larger playing areas. Clear evidence about the actual tactical behaviours emerging during SSCGs played on different field dimensions is needed, since it can lead to the design of specific affordances (invitations for selected actions; see Withagen, Poel, Araújo & Pepping, 2012) during practice and to the emergence of distinct learning opportunities, skills and decision-making.

A constraints-led approach advocates the need to understand the spatial-temporal relations emerging from the exploratory behaviours of players seeking to adapt to changing task demands (Passos et al., 2008). Some work by Frencken, van der Plaats, Visscher, and Lemmink (2013) has shown that reduced field length and width in SSCGs caused the players to close down space relative to each other, longitudinally and laterally, respectively. This was demonstrated through measurements of lateral and longitudinal distances between the teams' centres on pitches of varying sizes. Teams playing on different field sizes but with same length to width ratios also revealed performance differences due to different surface area values. The authors also argued that skilled players would be likely to establish stronger relations (depicted by stronger couplings between team centres) between each other due to their ability to anticipate movements of teammates and opponents. From an ecological dynamics perspective, expert behaviour in sport is conceptualised as the ability to functionally adapt to the dynamically changing interacting performance constraints perceived (Seifert, Button, & Davids, 2013). This means that manipulation of the same football training task constraints, with players of different skill levels, might also lead to the emergence of different tactical behaviours. As yet, there is limited understanding of how different field dimensions interact with players skill levels. This information can be useful for adapting task constraints to players of specific skill levels in order to optimize skill acquisition and provide insights on the tactical features that characterize distinct expertise levels.

Analyses of complex team behaviours displayed during SSCGs played in fields of varying dimensions are required to uncover the dynamic spatial-temporal relations between players (Vilar, Araújo, Davids, & Button, 2012) and describe specific tactical adaptations of players to field size constraints. From the perspective of the coverage of space, manipulations in field size may impact on the area covered by both teams, with larger dimensions possibly resulting in greater width coverage. The shape of the covered area may vary from elongated playing shapes to more flattened shapes according to field length and width dimensions. Recently, Folgado, Lemmink, Frencken, and Sampaio (2012) found different length per width ratios in teams of youth football players of different ages, with teams of younger players displaying higher length and lower width coverage. This shape indicated the preferred axis of expansion of the teams during match play, an important characteristic of space occupation that can be particularly useful for coaches seeking to enhance specific team tactical behaviours, like the goal-to-goal outstretched distribution, or the distribution of players to lateral zones of the field.

By covering different field areas, the interpersonal distances between teammates and their opponents may also vary, impacting on the collective decision-making behaviour of the players. Previous studies have highlighted the importance of interpersonal distances as a constraint on attacking play in football dyads (Duarte et al., 2010) and functional team coordination in rugby union (Passos et al., 2011).

In order to understand the collective movements of teams during play, analysis of the teams' centres (or centroids) trajectories might provide information about the synchronization of the two teams during attacking and defensive sub-phases. The centroid represents the relative position of the team on the field and its coupling has been revealed to be stronger in the longitudinal direction, both in SSCGs (Duarte, Araújo, Freire, et al., 2012; Frencken, Lemmink, Delleman, & Visscher, 2011) and full-sized matches (Bartlett, Button, Robbins, Dutt-Mazumder, & Kennedy, 2012). Furthermore, as discussed earlier, analyses of centroid coupling strength can provide insights on player expertise level.

Given this theoretical rationale, the aim of this study was twofold. First, we aimed to examine differences in team tactical behaviours when pitch dimensions are manipulated during SSCGs practice. Second, we sought to investigate how skill level impacts on the collective behaviours expressed. We expected that both field size and skill level would constrain different interpersonal interactive behaviours, and thus, lead to the emergence of different action possibilities and tactical adaptations.

5.2 Methods

5.2.1 Participants

Twenty male youth football players from two different clubs participated in this research study. Their skill level was determined according to their competitive performance level. Players from Club A (age: 16.20±0.63 yrs; playing experience: 6.6±1.65 yrs) competed at a national-level, whereas players from Club B (age: 15.60±0.52 yrs; playing experience: 6.2±2.35 yrs) competed in the 2nd division of their regional association football competition. Based on this criterion, participants were classified at either national-level (NLP) or regional-level (RLP) of performance. The study protocol was approved by the Ethics Committee of the Faculty of Sports of Porto University, Portugal.

5.2.2 Small-sided and conditioned games

Each group of players was assigned by their coaches to two teams of four players plus one goalkeeper that performed in three Gk+4 v 4+Gk SSCGs using 7-a-side football goals. The goalkeepers played inside an area marked five-meters from the goal line and extending across the field width. Passing the ball to the goalkeeper was not allowed in order to optimize offensive play by the outfield players. All SSCGs were played according to the other official rules of Association Football with the exception of the offside rule that was not applied.

Each SSCG had a duration of 7-min interspersed with 7-min of rest. During recovery periods, participants were allowed to recover actively at will and rehydrate. Coaches were instructed to not provide any sort of encouragement or feedback to the players as it could impact on the intensity of participant performance in SSCGs (Rampinini et al., 2007).

Each SSCG field dimension was calculated using official football field dimensions – 105 x 68 m as a reference. Length and width were reduced in proportion to the number of players involved in the SSCGs (Hughes, 1994), providing size estimates of the intermediate field - 47.3 x 30.6 (length x width). The small and large field measures were set by subtracting and adding 10% to the intermediate field measures, respectively. Thus, the small field was 36.8 x 23.8 m (length x width) and the large field was 57.8 x 37.4 m. A ratio of 1.5:1, as reported in official field measures, was maintained between length and width in all SSCGs.

The SSCGs were played in the small field first, followed by the intermediate and large fields (order set arbitrarily). This protocol was operationalized prior to the clubs' regular training sessions (both teams used to practice in the late afternoon) in the middle of the week (i.e., equally distant from the last and the next official team competitive fixture).

5.2.3 Data collection

Each outfield player carried an unobtrusive global positioning tracking device (SPI Pro, GPSports, Canberra, Australia) that captured the longitudinal and latitudinal movement coordinate time-series with a sampling frequency of 15 Hz. The reliability of such type of devices is well documented elsewhere (Coutts & Duffield, 2010; Johnston, Watsford, Pine, Spurrs, & Sporri, 2013).

All pitches used in the treatments were calibrated with the coordinates of four GPS devices stationed in each corner of the pitch for about 2 minutes. The absolute coordinates of each corner were calculated as the median of the recorded time series, providing measurements that were robust to the typical fluctuations of the GPS signals. These absolute positions were used to set the Cartesian coordinate systems for each pitch, with the origin placed at the pitch centre. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). Fluctuations in the players' positioning were reduced using a moving average filter with a time scale of 0.2 seconds and data resampling was employed to synchronize the time series of all players within each game.

5.2.4 Tactical variables

Team tactical behaviours were assessed by measuring: (i) the area of the effective playing space (EPS); (ii) the playing length per width ratio (PLpW); (iii) the teams' separateness (TS); (iv) the uncertainty of the distances separating each player from his nearest opponent; and (v), the teams' mutual dependency during collective lateral and longitudinal movements (see Figure 10-A for an illustration).

The effective playing space (EPS) represents the polygonal area defined by the players located at the periphery of play (Gréhaigne & Godbout, 2013) and was calculated (in m^2) by computing the area of the smallest convex hull containing all outfield players in the SSCG (goalkeepers excluded).

The PLpW represents the relationship between the playing length and width and describes the preferable axis direction towards which the players from both teams are distributed, that is, the preferable shape of the match. In this study, an elongated playing shape was considered for values of PLpW above 1.3 (width representing ≈75% of length), whereas values below 0.7 indicated a flattened playing shape (length representing ≈75% of width). Values of PLpW ranging between 0.7 and 1.3 were considered to represent an identical distribution of players in both axes.

The TS was defined as a measure of the degree of free movement each team has available. It was computed by organizing the distances between opponent players in a pair-wise distance matrix *M(t)* of order 16 (4 x 4 players, excluding goalkeepers). The TS for a team was defined as the sum of distances between each team player and the closest opponent. This measure has units of meters and can be interpreted as the overall radius of action free of opponents. A measure of TS was preferred to other metrics such as the centroids' distance to measure the closeness of the teams' players since the latter does not account for the teams' dispersion differences which may impact on the players' radius of free movement. A value of TS close to 0 indicates that all players are closely marked, while a high value indicates more freedom of movement.

The uncertainty of interpersonal distances values throughout the duration of SSCGs was also analysed by means of sample entropy measures (SampEn). SampEn(*m, r, N*) is defined as the negative natural logarithm of the conditional probability that two sequences, similar for *m* points (length of the vector to be compared), remain similar at the next point *m + 1* (Richman & Moorman, 2000). The similarity criterion is set by $r\times$SD of the time-series. Given the analysed time series length (840 data points), the parameter combination used in this study was $m = 2$ and $r = 0.1$. The structure of variability was reflected by values of SampEn ranging between 0 towards infinity where 0 represents a perfectly repeatable time series and infinity is a totally unpredictable time series. From this quantity we could infer the unpredictability present in each competing dyad.

The mutual dependency between the collective movements of the two teams (for longitudinal and lateral movements) was calculated by measuring the nonlinear correlation of the two centroids' movements as the average mutual information (AMI). The calculation of the AMI is grounded in the measure of mutual information:

$$\mathrm{I(X;Y)} = \sum_{\mathrm{X,Y}\in\mathcal{A}} \mathrm{P(X,Y)}\log\left(\frac{\mathrm{P(X,Y)}}{\mathrm{P(X)P(Y)}}\right) \tag{4}$$

Where X and Y represent each team's centroid movement coordinates and $\mathcal{A}$ is the space discretization, defined by the space binning, from which X and Y take their values (Cover & Thomas, 1991). The AMI was used to identify and characterize relationships between data sets that are not detected by linear measures of correlation. It was provided with normalized values ranging between 0 and 1, where 0 occurs if, and only if, the time series of the two centroids' coordinates, X and Y, are independent. Non-zero values account for the reduction in uncertainty about one team's centroid location, given knowledge of the other team's centroid value. A value of 1 represents total predictability of one centroid's movements, from the knowledge of the other centroid's movements.

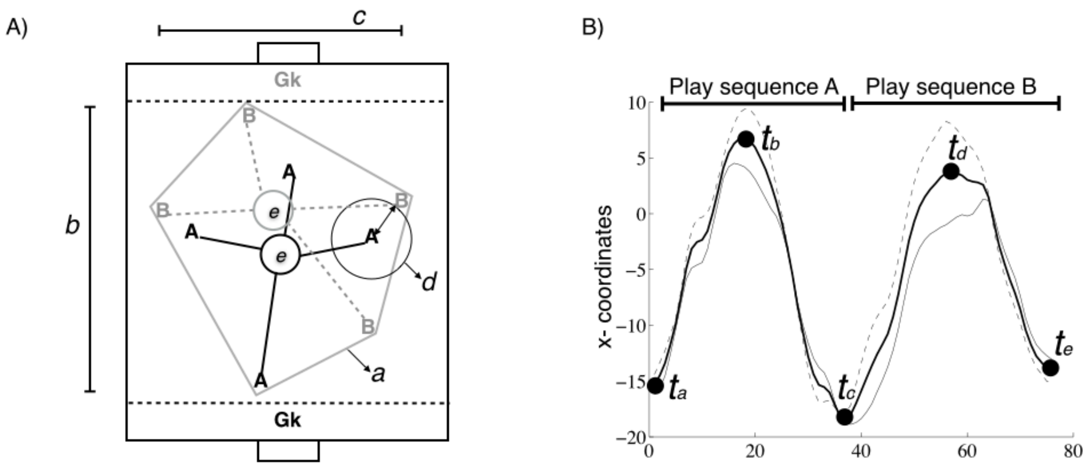

Figure 10 - A) Graphical illustration of the variables used: *a* illustrates the effective playing space, *b/c* was calculated for playing length per width ratio, *d* depicts an example of a radius of action free of opponents and *e* shows the centroids of each team. **B)** Exemplar time series of the total match centroid (solid black line) and each team's centroids (dashed and solid grey lines) longitudinal movements in one SSCG condition. The periods encompassing three time points (e.g., dots t_a: t_c and so on) correspond to movements of the teams towards both goals (t_a: t_b towards team B's goal and t_b : t_c towards team A's goal).

5.2.5 Statistical analysis

The rate of change of all variables was below 2 m/s and 2 m/s^2 (velocity and acceleration, respectively). Thus, a sampling rate of 2 Hz was considered appropriate to capture the variables' time-variations under the differing pitch and skill conditions.

For statistical analysis purposes, the mean values of the variables EPS, PLpW, TS and the AMI values of the teams' centroids were recorded during several playing sequences in each SSCG. Each sequence captured the ebb-and-flow rhythm of the games in which the total match centroid (depicted as the mean x- and y- coordinates of all players on the field) transited the pitch in both directions (goal-to-goal) during coordinated longitudinal movements of both teams on field (Figure 10-B). During such playing sequences, both teams maintained possession of the ball and attacked the opposing team's goal alternately. In each trial, the eight longest cycles were identified and recorded for analysis. The overall average period duration was 40.5±14.3 seconds (*M*±*SD*) with no duration differences found between groups (*p*=0.88) neither treatments (*p*=0.91). The coefficients of variation of the analysed variables for all periods were below 30% and also revealed no differences in data dispersion between SSCGs and groups (p>0.05 for all variables). Thus, it was assumed that data were identically distributed in all periods and treatments.

All values of EPS, PLpW, TS, AMI and SampEn were then subjected to two-way ANOVAs to identify possible differences between skill-level groups and SSCGs formats. Effect sizes were reported as partial eta squared (η^2) and, whenever justified, pairwise differences were followed-up using Bonferroni post hoc adjustment.

5.3 Results

Table 3 resumes the mean ± standard deviations of all variables plus the relative standard error of the mean (RSE) and Figure 11 shows values of EPS, PLpW, TS, and SampEn across SSCGs and expertise groups.

EPS increased with field dimension for both groups, as expected. Results revealed a main effect of SSCG, F=70.96, p<0.001, η^2=0.78, with mean values differing significantly between all treatments (p<0.001 for all pairwise comparisons, SE=0.88).

The PLpW revealed an interaction effect, F=4.14, p=0.02, η^2=0.17, with the NLP displaying significantly higher values than the RLP on the large field condition (p=0.007) and was close to conventional levels of statistical significance (p=0.06) in the intermediate field condition. Results indicated an elongated playing shape for the NLP in the intermediate and large fields (values of PLpW above 1.3). Additionally, the NLP revealed marked differences between performance on the small and the intermediate field (p<0.001) and between the small and the large field (p<0.001), while the RLP did not present statistically significant differences between any of the field conditions.

The TS exhibited the same trend as EPS, observable in Figure 11-C. The ANOVA results revealed a main effect for SSCG, F=36.84, p<0.001, η^2=0.65, with TS values increasing with field dimension as well. Statistically significant differences were found between all treatments (p<0.001 for all pairwise comparisons, SE=0.82).

Table 3 – Variables mean ± standard deviation (M±SD) plus relative standard error of the mean (RSE) according to skill level and field dimension.

Groups	Variables	Small field		Intermediate field		Large field	
		M ±SD	RSE (%)	M ±SD	RSE (%)	M ±SD	RSE (%)
Regional-level players	TS	17.62 ±2.12	±4.25	21.48 ±2.2	±3.62	25.28 ±3.32	±4.97
	EPS	119.50 ±13.45	±3.98	168.17 ±19.33	±4.06	247.67 ±44.64	±6.81
	PLpW	1.06 ±0.07	±2.21	1.18 ±0.28	±8.25	1.14 ±0.22	±7.30
	AMI (longitudinal)	0.53 ±0.07	±4.38	0.54 ±0.09	±6.00	0.61 ±0.13	±7.98
	AMI (lateral)	0.43 ±0.09	±7.05	0.45 ±0.07	±5.53	0.45 ±0.16	±13.06
	SampEn	1.08 ±0.08	±2.63	0.98 ±0.09	±3.16	0.88 ±0.1	±4.35
National-level players	TS	17.47 ±1.72	±3.48	20.89 ±1.58	±2.87	23.94 ±2.46	±3.64
	EPS	121.16 ±24.55	±7.36	175.08 ±16.06	±3.47	251.2 ±46.33	±6.52
	PLpW	0.96 ±0.15	±5.53	1.39 ±0.22	±6.09	1.45 ±0.24	±5.84
	AMI (longitudinal)	0.53 ±0.09	±5.87	0.53 ±0.08	±5.83	0.54 ±0.12	±7.47
	AMI (lateral)	0.45 ±0.07	±5.53	0.43 ±0.05	±4.71	0.40 ±0.18	±16.24
	SampEn	1.25 ±0.09	±3.47	1.12 ±0.14	±4.87	0.86 ±0.11	±4.37

TS – team separateness; EPS – effective playing space; PLpW – playing length per width ratio; AMI (longitudinal) – centroids' average mutual information in the longitudinal direction; AMI (lateral) – centroids' average mutual information in the lateral direction; SampEn – sample entropy of distance to nearest opponent.

Analysis of the SampEn values of the distances to nearest opponents revealed an interaction effect for skill level and SSCG, F=3.76, p=0.03, η^2=0.15. NLP displayed significantly larger values in the small (p=0.003, SE=0.06) and intermediate fields (p=0.01, SE=0.06) than RLP, whereas in the large field, values of both groups were approximate (Figure 11-D). The NLP presented statistically significant entropy differences between all treatments (p<0.05 for all pairwise comparisons), whereas RLP only decreased their SampEn values significantly when comparing the small with the large field treatments (p=0.001, SE=0.05). A main effect for SSCG, F=30.13, p<0.001, η^2=0.59, was also found, with entropy values decreasing as field size increased.

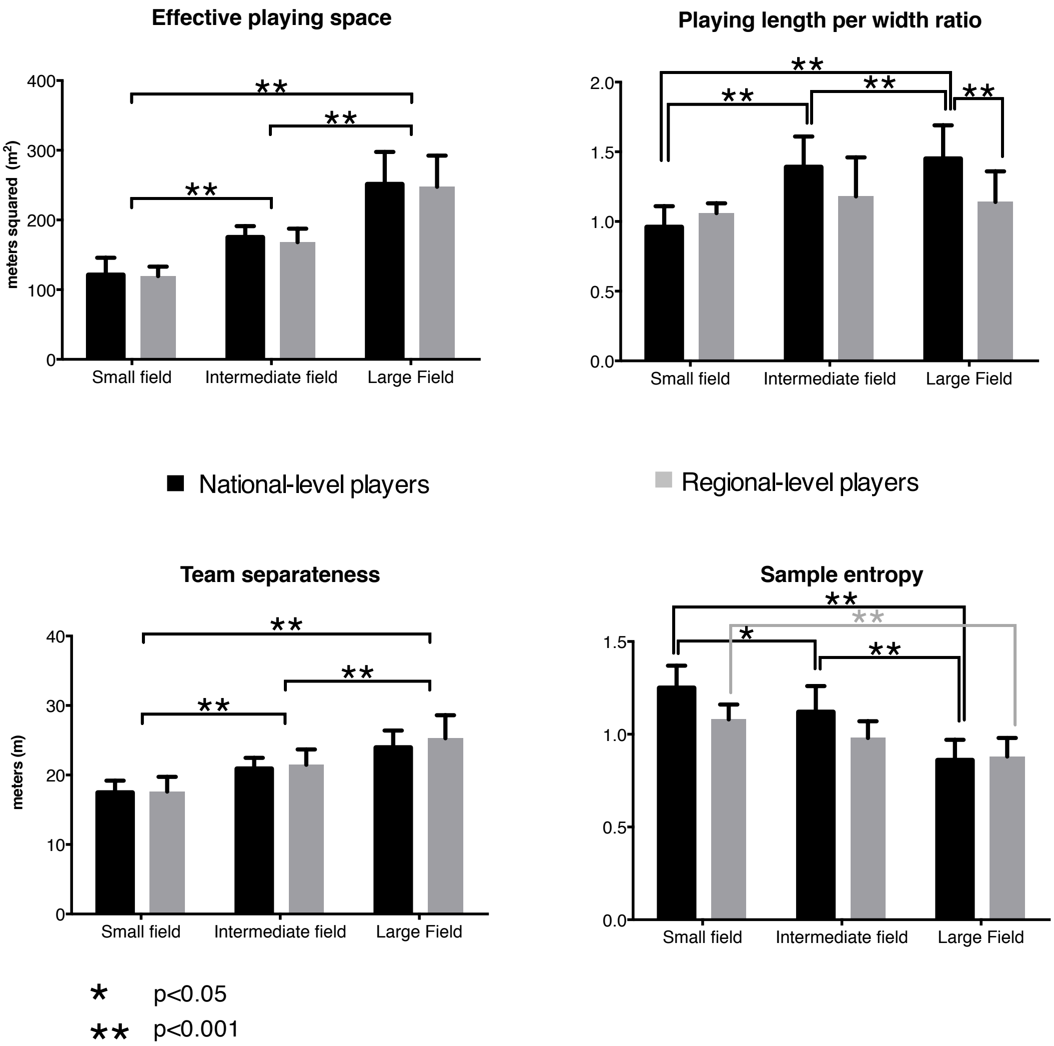

Figure 11 – Mean values of the effective playing space (A), playing length per width ratio (B), team separateness (C) and sample entropy (D) according to field size (small, intermediate and large fields) and skill level (national- and regional-level players). Error bars represent standard deviation.

Regarding the AMI values of both teams' centroids movements, Figure 12 verifies that the centroids' mutual dependence is slightly higher on longitudinal movements than in lateral movements with both values having remained relatively stable across conditions for both groups. No statistically significant differences were observed between SSCGs, (goal-to-goal: F=1.03, p=0.36, η^2=0.04; side-to-side: F=0.08, p=0.91, η^2=0.004), nor between groups (goal-to-goal: F=1, p=0.32, η^2=0.02; F=0.2, p=0.65, η^2=0.05) for any of the centroids' movement directions.

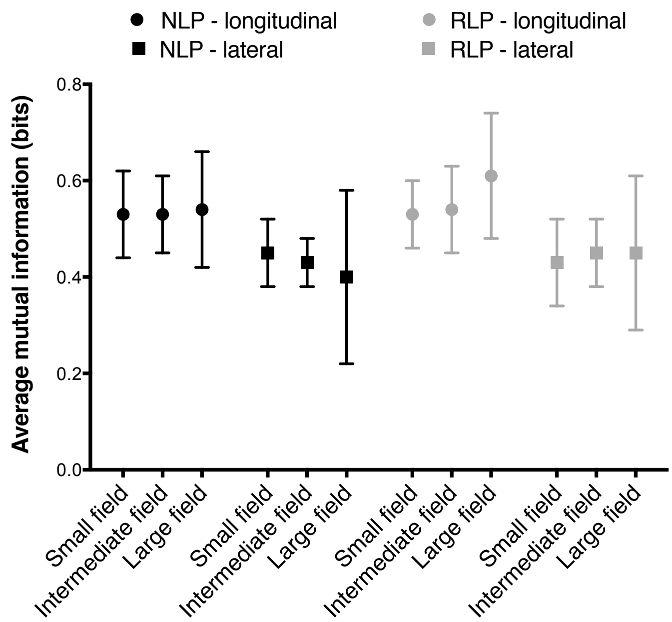

Figure 12 – Average mutual information values of the centroids' movements according to SSCG format (small, intermediate and large fields), skill level (national- and regional-level players) and axis (longitudinal and lateral directions). Error bars represent standard deviation.

5.4 Discussion

Different types of SSCGs are frequently used in football training sessions and have been widely studied from a physiological performance viewpoint. This study aimed to extend knowledge on the influence of SSCGs in tactical performance by providing information about adaptations of teams' collective behaviours displayed by players of different skill levels during SSCGs played on fields of varying size.

In general, results confirmed our initial expectations that different field sizes and skill levels constrain different team tactical adaptations in SSCGs.

As expected, the EPS increased with field dimension, with teams covering a significantly wider area of play on larger fields. This area almost tripled from the smaller to the largest field dimension but without any differences for skill level. The main difference between the two groups was found in the playing shape assumed in the different fields. While the RLP maintained similar PLpW values across conditions, the NLP evidenced a more elongated playing shape in the intermediate and large fields, which might be seen as a strategy to approach the goals more quickly in larger areas by playing preferably outstretched in the goal-to-goal direction. Increased EPS areas and elongated playing shapes might also have constrained different playing styles, for instance, with teams performing a higher number of long passes. Grant, Williams, Dodd, and Johnson (1999) previously reported significantly more long passes performed in youth football games played in larger field areas, which corroborates this assumption. This hypothesis should be further examined in future studies, however.

PLpW values observed in the small field were similar to those reported by Folgado et al. (2012) for intra-team length per width ratios in U-13 players. They used 30 x 20 m field measures that closely matched field dimensions in this study. However, they found larger intra-team length per width ratios (elongated playing shapes) in younger age groups (under-9s). A possible reason might be a different relation of pitch size and the sphere of action capacity of each age group. Younger participants are not able to cover the same amount of space per time unit as older participants, due to obvious body size, physical and maturational differences (Harley et al., 2010; Mendez-Villanueva, Buchheit, Simpson, & Bourdon, 2013). For instance, Buchheit, Mendez-Villanueva, Simpson, and Bourdon (2010) showed that match running performance (total distance covered, low intensity running, high-intensity running, very high-intensity running and sprinting) increases with age. This might have constrained a preference for a larger dispersion in the longitudinal direction to facilitate an approach towards goal in younger participants. In this study, given the age of our participants, the elongated shape displayed by the NLP in larger fields does not seem to be related to physical constraints. More knowledge is needed to understand the advantages of playing in this type of team shape.

The TS also increased with field dimension, meaning that players were further away from their nearest opponents as the area of play increased. This result is in agreement with the findings of Frencken et al. (2013) that showed the centroids' distance to be higher in larger fields, both longitudinally and laterally. By enlarging distances to nearest opponents, manipulations of field dimension may also shape the emergence of affordances (opportunities) to shoot, pass and dribble. It is expected that larger spaces facilitates, at least, the emergence of affordances for assembling successful passes by augmenting the distances of opponents to ball trajectories (Travassos et al., 2012; Vilar, Araújo, Davids, Correia, et al., 2012). Larger playing areas may also not provide affordances for players to dribble as they are offered less risky behavioural options (e.g., passing the ball to a free teammate in space). Additionally, dribbling actions seem to emerge at smaller values of interpersonal distances to opponents (Duarte et al., 2010). Shooting opportunities may be additionally constrained by the distance to goal, which is clearly affected by field dimension. Previous research has reported shots to occur more frequently on smaller pitches (Dellal et al., 2012; Kelly & Drust, 2009), probably because of reduced distances of players to goals. Further studies are needed to clarify what specific game actions are afforded with increased TS.

Although there were no observed differences between groups in TS, when the unpredictability of each player's distance to his nearest opponent was considered, the NLP presented significantly more unpredictable distance values than RLP in the small and intermediate fields. The same aforementioned studies have shown that, on smaller pitches, more tackles, challenges, loss of ball possessions and physical contact occurs (Dellal et al., 2012; Kelly & Drust, 2009). Therefore, a possible reason for the higher unpredictability displayed by NLP for distances to nearest opponents in smaller areas may be related to their superior ability to perform "off-the ball" movements more often in an attempt to get unmarked and create free space in order to maintain ball possession (Lervolino, 2011) while at the same time, the defenders try to restrict space available to their direct opponents.

With regards to the teams' coupling tendencies, the nonlinear dependency found between the teams' centroids was slightly superior for movements in the longitudinal direction in both groups confirming results from previous studies in regular matches (Bartlett et al., 2012; Yue, Broich, Seifriz, & Mester, 2008) and SSCGs (Frencken et al., 2011; Frencken et al., 2013). Both groups maintained similar levels of mutual dependency on movement trajectories across SSCGs. Thus, our data did not confirm the assumption advanced by Frencken et al. (2013) that expertise level could impact on the coupling relations between players or, perhaps, the teams' centroids do not capture the essentials of synchronization tendencies between players.

5.5 Conclusions and practical applications

SSCGs played on fields of different dimensions clearly constrained different interpersonal interactive behaviours in players of distinct skill levels. Increases in field dimensions promoted similar larger playing areas and similar larger distances between direct opponents in both groups. However, the more skilled players tended to adapt differently to the SSCGs since, without specific instructions, they assumed an elongated playing shape when the playing area increased. They also presented higher unpredictable values of distances to immediate opponents, which was interpreted as a strategy for creating space and avoid close marking.

Different playing shapes and distances to immediate opponents might promote affordances to adopt different playing styles like, for instance, performing more long passes when playing outstretched in the goal-to-goal direction on a larger field or more dribbling actions when playing in smaller fields. These assumptions should be verified in future studies aiming to capture the possibilities for action provided with such tactical adaptations.

The message for coaches is that collective tactical behaviours are flexible and can be shaped intentionally by manipulating simple variables like field dimensions. Through such manipulations coaches can minimally control the size of the effective playing space, its shape and the available space between players (teammates and opponents), and thus, constrain the emergence of affordances as different tactical adaptations while specifying the precise nature of task constraints in SSCGs.

Ultimately, SSCGs may be used as a performance development and evaluation tool for the identification and recruitment of players with emerging talent in football. The more skilled players seem to explore the available space differently and to be more difficult to mark.

5.6 References

Araújo, D., Davids, K., Bennett, S., Button, C., & Chapman, G. (2004). Emergence of sport skills under constraints. In M. Williams & N. Hodges (Eds.), *Skill acquisition in sport research, theory and practice* (pp. 409-433). UK: Routledge.

Bartlett, R., Button, C., Robbins, M., Dutt-Mazumder, A., & Kennedy, G. (2012). Analysing team coordination patterns from player movement trajectories in soccer: Methodological considerations. *International Journal of Performance Analysis in Sport, 12*, 398-424.

Buchheit, M., Mendez-Villanueva, A., Simpson, B.M., & Bourdon, P.C. (2010). Match running performance and fitness in youth soccer. *International Journal of Sports Medicine, 31*, 818-825.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sides soccer games: Effects of pitch size. *Journal of Sports Sciences 28*(14), 1615-1623. doi: 10.1080/02640414.2010.521168

Coutts, A.J., & Duffield, R. (2010). Validity and reliability of gps devices for measuring movement demands of team sports. *Journal of Science & Medicine in Sport, 13*(1), 133-135.

Cover, T., & Thomas, J. (1991). *Entropy, relative entropy and mutual information*. Hoboken, NJ: John Wiley and Sons, Inc.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews, 41*(3), 154-161.

Dellal, A., Owen, A., Wong, D.P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. Large sided games in relation to playing position in elite soccer. *Human Movement Science, 31*(4), 957-969.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sport teams as superorganisms: Implications of biological models for research and practice in team sports performance analysis. *Sports Medicine, 42*(8), 633-642.

Duarte, R., Araújo, D., Davids, K., Travassos, B., Gazimba, V., & Sampaio, J. (2012). Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes in youth soccer. *Journal of Sports Sciences, 30*(9), 871-877.

Duarte, R., Araújo, D., Freire, L., Folgado, H., Fernandes, O., & Davids, K. (2012). Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. *Human Movement Science, 31*(6), 1639-1651.

Duarte, R., Araújo, D., Gazimba, V., Fernandes, O., Folgado, H., Marmeleira, J., & Davids, K. (2010). The ecological dynamics of 1v1 sub-phases in association football. *The Open Sports Sciences Journal, 3*, 16-18.

Folgado, H., Lemmink, K., Frencken, W., & Sampaio, J. (2012). Length, width and centroid distance as measures of teams tactical performance in youth football. *European Journal of Sport Science, 14*(Sup1), S487-S492.

Frencken, W., Lemmink, K., Delleman, N., & Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science, 11*(4), 215-223.

Frencken, W., van der Plaats, J., Visscher, C., & Lemmink, K. (2013). Size matters: Pitch dimensions constrain interactive team behaviour in soccer. *Journal of Systems Science and Complexity, 26*(1), 85-93.

Grant, A., Williams, M., Dodd, R., & Johnson, S. (1999). Physiological and technical analysis of 11v11 and 8v8 youth football matches. *Insight, 2*(3), 3-4.

Gréhaigne, J.-F., & Godbout, P. (2013). Colective variables for analysing performance in team sports. In T. McGarry, P. O'Donoghue & J. Sampaio (Eds.), *Routledge handbook of sports perfomance analysis* (pp. 101-114). Oxon: Routledge.

Handford, C., Davids, K., Bennett, S., & Button, C. (1997). Skill acquisition in sport: Some applications of an evolving practice ecology. *Journal of Sports Sciences, 15*, 621-640.

Harley, J., Barnes, C., Portas, M., Lovell, R., Barrett, S., Paul, D., & Weston, M. (2010). Motion analysis of match-play in elite U12 to U16 age-group soccer players. *Journal of Sports Sciences, 28*(13), 1391-1397.

Hill-Haas, S., Dawson, B., Impellizzeri, F.M., & Coutts, A.J. (2011). Physiology of small-sided games training in football. A systematic review. *Sports Medicine, 41*(3), 199-220.

Hughes, C. (1994). *The football association coaching book of soccer tactics and skills*. Harpenden: Queen Anne Press.

Johnston, R., Watsford, M., Pine, M., Spurrs, R., & Sporri, D. (2013). Assessment of 5 hz and 10 hz gps units for measuring athlete movement demands. *International Journal of Performance Analysis in Sport, 13*, 262-274.

Kelly, D., & Drust, B. (2009). The effect of pitch dimensions on heart rate responses and technical demands of small-sided soccer games in elite players. *Journal of Science and Medicine in Sport, 12*(4), 475-479.

Lervolino, A. (2011). The creation of space. Principles and practice. *Soccer Journal, 56*(3), 31-32.

Mendez-Villanueva, A., Buchheit, M., Simpson, B., & Bourdon, P.C. (2013). Match play intensity distribution in youth soccer. *International Journal of Sports Medicine, 34*, 101-110.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Milho, J., & Serpa, S. (2008). Information-governing dynamics of attacker-defender interactions in youth rugby union. *Journal of Sports Sciences, 26*(13), 1421-1429.

Passos, P., Milho, J., Fonseca, S., Borges, J., Araújo, D., & Davids, K. (2011). Interpersonal distance regulates functional grouping tendencies of agents in team sports. *Journal of Motor Behavior, 43*(2), 155-163.

Rampinini, E., Impellizzeri, F.M., Castagna, C., Abt, G., Chamari, K., Sassi, A., & Marcora, S.M. (2007). Factors influencing physiological responses to small-sided soccer games. *Journal of Sports Sciences, 25*(6), 659-666.

Richman, J., & Moorman, R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *Am J Physiol Heart Circ Physiol, 278*, H2039-H2049.

Seifert, L., Button, C., & Davids, K. (2013). Key properties of expert movement systems in sport. *Sports Medicine, 43*, 167-178.

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*, 765-772.

Sinnott, R.W. (1984). Virtues of the haversine. *Sky and Telescope, 68*(2), 159.

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychology of Sport & Exercise, 13*(2), 216-223.

Vilar, L., Araújo, D., Davids, K., & Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Medicine, 42*(1), 1-10.

Vilar, L., Araújo, D., Davids, K., Correia, V., & Esteves, P. (2013). Spatial-temporal constraints on decision-making during shooting performance in the team sport of futsal. *Journal of Sports Sciences, 31*(8), 840-846.

Withagen, R., Poel, H.J.d., Araújo, D., & Pepping, G.-J. (2012). Affordances can invite behavior: Reconsidering the relationship between affordances and agency. *New Ideas in Psychology, 30*, 250-258.

Yue, Z., Broich, H., Seifriz, F., & Mester, J. (2008). Mathematical analysis of a soccer game. Part ii: Energy, spectral and correlation analyses. *Studies in Applied Mathematics, 121*, 245-261.

Chapter 6

Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams [10]

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Abstract

Similar to other complex systems in nature (e.g., a hunting pack, flocks of birds), sports teams have been modeled as social neurobiological systems in which interpersonal coordination tendencies of agents underpin team swarming behaviors. Swarming is seen as the result of agent co-adaptation to ecological constraints of performance environments by collectively perceiving specific possibilities for action (affordances for self and shared affordances). A major principle of invasion team sports assumed to promote effective performance is to outnumber the opposition (creation of numerical overloads) during different performance phases (attack and defense) in spatial regions adjacent to the ball. Such performance principles are assimilated by system agents through manipulation of numerical relations between teams during training in order to create artificially asymmetrical performance contexts to simulate overloaded and underloaded situations. Here we evaluated effects of different numerical relations differentiated by agent skill level, examining emergent inter-individual, intra- and inter-team coordination. Groups of association football players (national – NLP and regional-level – RLP) participated in small-sided and conditioned games in which numerical relations between system agents were manipulated (5v5, 5v4 and 5v3). Typical grouping tendencies in sports teams (major ranges, stretch indices, distances of team centers to goals and distances between the teams' opposing line-forces in specific team sectors) were recorded by plotting positional coordinates of individual agents through continuous GPS tracking. Results showed that creation of numerical asymmetries during training constrained agents' individual dominant regions, the underloaded teams' compactness and each teams' relative position on-field, as well as distances between specific team sectors. We also observed how skill level impacted individual and team coordination tendencies. Data revealed emergence of co-adaptive behaviors between interacting neurobiological social system agents in the context of sport performance. Such observations have broader implications for training design involving manipulations of numerical relations between interacting members of social collectives.

Keywords: social neurobiological systems; constraints; interpersonal coordination tendencies; co-adaptation; affordances; sports teams; numerical relations; skill level.

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[10] Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D. & Garganta. J. (2014). Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams. *PLoS ONE, 9*(9), e107112.

6.1 Introduction

Collective organizational principles underlying emergence of functional behaviors have been identified in many groups of biological organisms (e.g., flocks of birds, wolf packs, ant colonies) (Duarte et al., 2012; Sumpter, 2006). Observations of such superorganismic systems have revealed some advantages of swarming behaviors to achieve group goals, such as when feeding and maintaining member security. For instance, the labor of thousands of bees in a colony is collectively coordinated so that surrounding areas are surveyed most efficiently for food sources of nectar and pollen (Kesebir, 2012).

Human groups can also be considered as swarming superorganisms when individuals cooperate and coordinate their actions together to achieve common collective goals (Stearns, 2007). This sociobiological perspective can help explain various social-psychological phenomena such as the organization of labor by workers in a factory, how a traffic jam arises or the interpersonal rhythmic movements characterizing human activities like dancing or marching together.

Recently, this approach has been implemented to understand how interacting individuals coordinate their movements by detecting sensory information like the visual movement of others (see Marsh et al., 2006; Richardson et al., 2007; Schmidt & Richardson, 2008; Sebanz et al., 2006, as examples). Despite its obvious relevance, joint actions in the human performance domain of team sports has not received the same amount of empirical attention (Hristovski et al., 2011).

An *ecological dynamics* perspective to understand coordination in team sport social collectives views competing performers as biological agents functioning in integrated systems composed of many interacting subsystems (attackers and defenders) that can harness inherent self-organization tendencies to satisfy specific performance environment constraints (Davids et al., 2006; Passos et al., 2013). From this theoretical rationale, sports teams have been modeled as social neurobiological systems whose agents co-adapt behaviors to changing ecological constraints of performance environments to achieve competitive goals (Button et al., 2012; Passos, Araújo, et al., 2009).

These theoretical ideas have implications for current training methodologies in team sports systems seeking to promote activities of individual agents into functional coordinated performance modes needed to achieve effective competitive performance. A major principle that is paramount to achieve competitive performance goals in invasion games (like association football) is the coordinated effort to create numerical superiority in the vicinity of the ball (a type of swarming behavior) in attacking and defending sub-phases of play (Teodorescu, 1977; Worthington, 1974). The relevance of this universal principle for successful performance in team sports was elucidated in studies of interpersonal coordination tendencies in competing agents by Vilar et al. (2013). They analyzed tendencies to maintain offensive and defensive numerical superiority in specific spatial sub regions of the performance environment by creating sudden defensive stabilities and offensive opportunities through collective behaviors during competitive football matches. More successful performance outcomes during attacking and defending sub-phases of play were directly related to the relative number of opposing players adopting a spatial location nearer to the ball (see Vilar et al., 2013).

The creation of local numerical superiority through collective swarming behaviors when teams possess equal numbers of players is difficult to achieve without effective team coordination developed during training. To heighten awareness of such emergent interpersonal coordination tendencies during performance, coaches seek to simulate numerical asymmetries by designing training programs in which an attacking team is overloaded and a defending team is underloaded, respectively, containing more and fewer players. In such training practices, players learn to explore the interpersonal interactions that shape how different numerical relations can be suddenly created during attacking and defending sub-phases of play. In team sports training programs, small-sided and conditioned games (SSCGs) provide an important task vehicle used to constrain the emergence of interpersonal tactical behaviors in system agents through manipulations of numerical relations (in this paper such practice tasks are designated as small-sided “*and conditioned”* games because other constraints, besides field dimension, can be manipulated in order to shape specific behaviors; e.g., player numbers, rules, etc.).

The theoretical reasoning behind use of SSCGs is that they are simulations created during training to help team sports players to learn how to satisfy different constraints on their emergent collective behaviors. Indeed, they are important vehicles to aid sports teams, as complex neurobiological systems, to exploit inherent tendencies for co-adaptation and self-organization (Duarte et al., 2012; Silva et al., 2013). These properties of complexity have also been used to explain how agents in social neurobiological systems evolve and adapt their behaviors to satisfy evolutionary constraints (Passos, Araújo, et al., 2009). Like such systems, players in sports teams use functional, context-dependent information to regulate their collective behaviors in dynamic performance environments. Previous research suggests that these emergent interpersonal coordination tendencies are predicated on perception of the action possibilities of nearby players (Button et al., 2012; Passos et al., 2011) and the ball’s displacement over space and time (Travassos et al., 2011), which *afford* specific actions (Withagen et al., 2012).

The concept of a*ffordances,* as originally postulated by Gibson (1979), refers to the possibilities for action that emerge from the interactions of an organism with its environment. This concept is useful for explaining emergence of interpersonal interactions in team sports since the ability to perceive action possibilities for self in humans is complemented by their capacity to perceive another individual’s *affordances* (Stoffregen et al., 1999) and intentions (Mark, 2007). As Gibson argued, the richest affordances are provided by interactions with others, since 'behavior affords behavior' (p135), signifying how the environment itself can also be perceived in relation to self and another person’s abilities (see Witt & Sugovic, 2012; Witt et al., 2012). Accordingly, an *ecological dynamics* approach advocates that the interpersonal synergies (Riley et al., 2011) established between system agents in sports teams can emerge through the perception of *shared affordances.* These are possibilities for action that players collectively perceive through their interacting behaviors with their colleagues and adversaries and that can be effectively designed into SSCGs (Araújo et al., in press; Davids et al., 2013). For instance, a ball carrier in a SSCG can perceive a possibility for passing the ball to an unmarked teammate by also perceiving for him/her a possibility to receive the ball. In this example, both coordinating players perceive *affordances* for one another. The coordinated action of passing and receiving a ball composes a *shared affordance* that is specified to individuals forming a single synergy in different ways (see Silva et al., 2013 for a detailed explanation on how shared affordances and synergies may form the basis of coordination of team tactical behaviors). Affordances are dynamic and coordination tendencies between interacting teammates, and between them and their opponents, can change due to the creation of overloads in attack and defense through swarming. In this sense, learning to suddenly outnumber the opposition by overloading in specific spatial areas of a SSCG training environment can help players to create numerical advantages by selectively picking up *shared affordances* that satisfy a team's momentary goals. This interactive process supports the emergence of swarming behaviors and the team's complex tactical performance (Araújo et al., in press). However, the tactical behaviors exhibited by agents in team sports, like association football, that emerge at the group level (i.e., when swarming), due to the creation of unbalanced numerical relations, have seldom been investigated. In one exception, Travassos et al. (2011) observed how, in the team sport of futsal, agents in a defending underloaded team, in a 5v4 + goalkeeper (gk) game context (a common situation where the goalkeeper of an attacking team plays as an outfield player to create a numerical advantage over a defending team), swarmed around the ball and protected their goal space. The players achieved this performance goal by synchronizing their own movements with the ball's lateral displacements in front of their own goal area. More information about team behaviors during asymmetrical game contexts is clearly needed. Such contexts emerge quite often in many team invasion games besides association football and futsal, such as waterpolo, rugby union, handball or hockey, when one player is 'sin-binned' or sent off temporarily or definitely. This information may be an asset for designers of team training programs to enhance understanding of emergent collective tactical behaviors, skill acquisition and decision-making as a consequence of the interplay of specific ecological constraints in a learning environment (Chow et al., 2011).

An important, related question concerns whether tactical behaviors emerging from manipulations of numerical relations between competing system agents might be influenced by performer skill level. Silva et al. (in press) demonstrated that players of distinct competitive levels displayed different spatial distributions and movement oscillations on field during SSCGs, as a consequence of their skill level. Hence, it is important to understand how players' skill levels, within the ecological constraints of specific performance environments, can influence the interpersonal coordination tendencies afforded by differing numerical relations during training in SSCGs.

Previous investigations of coordination tendencies in team sport systems have revealed a number of reliable individual and compound performance variables (Duarte et al., 2012) for assessing interpersonal coordination tendencies at different levels of system analysis (e.g. inter-individual, intra- and inter-team coordination levels).

Inter-individual coordination analyses have focused on cooperative tendencies amongst team members, providing information on the division of labor between agents (Eccles, 2010). For instance, recent work examined players' dominant regions in team sports of football and futsal by quantifying each individual's major ranges (Yue et al., 2008) and Voronoi cells (Fonseca et al., 2012), which depict the division of labor amongst team members. At a more macroscopic level of analysis, researchers have measured, for instance, teams' geometrical centers (or centroids) and stretch indices to assess intra-team coordination patterns (Duarte, Araújo, et al., 2013; Frencken et al., 2011). These variables provide complementary information about emergent agent coordination tendencies, with the centroid highlighting the relative position of one team on field and the stretch index plotting the dispersion of players around the team center. *Intra-team analyses* also support identification of different characteristics of the coordination tendencies within each of the opposing teams.

At a larger scale of analysis, inter-team coordination focuses on the coordination patterns emerging *between* opposing teams and highlights the competitive interactions between players and teams to achieve specific performance goals. Knowledge about inter-team coordination has been obtained, for example, by quantifying distances between competing teams' centroids during performance (Duarte, Fernandes, et al., 2013). An alternative to studying inter-team coordination tendencies involves analysis of specific sub-grouping alignments in sports teams, such as line-forces (Gréhaigne et al., 1997; Grehaigne & Godbout, 1995). Line-forces provide (geometrically) an estimate of team cohesion (e.g., between players in a defensive line), representing the functional form in which players' attacking and defensive actions are co-aligned and co-organized according to specific team sectors (longitudinally, in attacking, midfield and defending team sectors or laterally, on the wings and middle axis of the field) (Gréhaigne, 1988). Through this conception, inter-team coordination tendencies can be studied according to specific sub-grouping alignments, by measuring the distance between competing lines of players on field.

To summarize, due to the lack of empirical work addressing effects of different numerical relations on coordination tendencies in systems of interacting team sports players, we sought to analyze tactical behaviors emerging from swarming tendencies in SSCGs. To achieve this aim, we investigated whether different numerical relations between competing teams in association football impacted inter-individual, intra- and inter-team tactical behaviors (i.e., emerging in overloaded and underloaded teams), as well as the relative influence of player skill level, specifically on the: (i) players' division of labor, (ii) teams' relative positioning on field; (iii) teams' dispersion; and (iv), inter-team distances at specific locations.

6.2 Methods

6.2.1 Participants

Twenty male, youth football players (under-19 yrs) participated in this study, divided into two groups according to skill level (NLP, national-level of performance or RLP - regional-level of performance). Ten participants in the NLP group (mean age: 17.64±0.67 yrs) played at a national-level in a top club from their country of origin (playing experience: 9.55±0.52 yrs). Two participants from this group played for their country's under-19 yrs national team. Participants in the RLP (age: 17.91±0.3 yrs) competed at a regional-level competition (playing experience: 9±1.9 yrs). All players or legal guardians (when under age) provided written informed consent to participate in the experiment. All procedures followed the guidelines stated in the Declaration of Helsinki and were approved by the Ethics Committee of the Faculty of Sports of Porto University.

6.2.2 Data collection

Within each group, participants were assigned to one of two technically-equivalent teams of five players by their coaches. Participants performed in three SSCGs in which the numerical relations of the two teams were manipulated. The first SSCG consisted of a 5-a-side plus goalkeeper (Gk) game (5v5+Gk). The goalkeepers played inside an area marked 5 m from the goal line and extending across the pitch width, while defending a 6 x 2 m (height x width) football goal. The team without a goalkeeper defended three mini-goals (1.2 x 0.8 m) located on the end line of the pitch. In the second and third SSCGs, the team playing with a goalkeeper was reduced to four (5v4+Gk) and three (5v3+Gk) outfield players, respectively. In accordance with pedagogical principles, this team was denominated the *underloaded* team, while the team with the same number of players was denominated the *overloaded* team. The objective of teams in all SSCGs was to score as many goals as possible and to prevent the opposing team from scoring goals (regardless of numerical overloaded or underloaded performance conditions and of the momentary score in the SSCG). The underloaded team attacked mini-goals without goalkeepers to maintain their chances of scoring when playing with a numerical disadvantage. Table 4 shows that both groups performed a similar number of shots and goals in all treatments. The effectiveness of the shots of both skill groups' underloaded teams confirms that, even when playing under a disadvantage of two fewer players, the chances of scoring were high (given that there was no GK). Effectively, there existed an attacking risk to the overloaded teams when possession was lost.

Table 4 – Number of shots and goals obtained by teams on each of the small-sided and conditioned games (SSCGs), according to skill.

SSCGs	National-level players				Regional-level players			
	Overloaded team		Underloaded team		Overloaded team		Underloaded team	
	Shots	Goals	Shots	Goals	Shots	Goals	Shots	Goals
5v5	6	1	4	4	3	2	4	4
5v4	8	2	2	2	8	3	2	2
5v3	11	5	4	4	12	5	5	5

The teams attacking the goal with a goalkeeper (overloaded teams) performed more shots in all treatments, with the exception of the regional-level players in the 5v5 treatment. The teams defending mini-goals (overloaded teams) always lost when playing under balanced numerical relations. This reflects the larger risks taken by this team defending goals without a goalkeeper. The underloaded teams performed fewer shots but the opportunities to shoot always ended in goals, depending only on the skill of the player to hit the target after a shooting opportunity was created.

The length and width dimensions of the playing area were reduced, relative to official football field dimensions, to 47.3 x 30.6 m, given the number of players involved in the SSCG (Hughes, 1994). Each match lasted for 6 minutes interspersed with 6 minutes periods of rest to minimize the influence of fatigue on participants. During recovery periods, participants were allowed to recover actively at will and rehydrate. Time-motion analysis obtained through continuous GPS tracking showed similar physical profiles across treatments for the players of the overloaded teams. The players of the underloaded teams tended to augment the total distance covered and high intensity running activities when playing under a numerical disadvantage of two players (5v3 + Gk). These data signaled that accumulated fatigue of participants did not bias the results of the experiment.

Coaches were instructed not to provide any sort of encouragement or feedback to the players, before and during periods of data collection, as it could have distorted levels of practice intensity in individual participants (Rampinini et al., 2007).

All outfield players carried an unobtrusive global positioning tracking device (SPI Pro, GPSports, Canberra, Australia) to record their movement displacements with individual positional data (2D) at a sampling frequency rate of 15 Hz. The reliability of such devices has been previously well documented (Coutts & Duffield, 2010; Johnston et al., 2013).

The performance area used in all treatments was calibrated with the coordinates of four GPS devices stationed in each corner of the pitch for approximately 2 minutes. The absolute coordinates of each corner were calculated as the median of the recorded time series, providing measurements that were robust to the typical fluctuations of the GPS signals. These absolute positions were used to set the Cartesian coordinate systems for each pitch, with the origin placed at the pitch center. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). Fluctuations in player positioning measures were reduced using a moving average filter with a time scale of 0.2 seconds and data resampling was employed to synchronize the time series of all players within each game.

6.2.3 Data analysis

Inter-individual coordination tendencies were analyzed measuring the dominant region of each player on field. To this effect, the major ranges of each player's displacement were calculated as the ellipse centered at the 2D mean location of each player (i.e., the locus), with semi-axes being the standard deviations in the longitudinal and lateral directions for each entire SSCG (Yue et al., 2008). Analysis of ellipse shapes provides qualitative evaluation of the main directions of players' movements, their distribution and relative positioning on field. The areas of the ellipses were also calculated to furnish quantitative information of the amount of space that was under the dominant region of each player.

To establish intra-team coordination we calculated the stretch index (SI) and the centroid's distance to the goal center (CdtG – in the case of the underloaded team) and to the end line where the mini-goals were placed (CdtMG – in the case of the overloaded team). The SI was calculated as the mean value of the distances of each player to their team's centroid, whereas the centroid was calculated as the average position of all outfield players of one team.

Inter-team coordination was examined through analysis of the distances separating the teams' horizontal and vertical opposing line-forces. We opted to record this variable instead of measurements of centroid distance values because the former does not capture the existence of eventual differences in the players' interactive behaviors at specific team locations (e.g., wings and sectors).

Each team's horizontal lines were calculated by averaging the longitudinal coordinate values of the two players furthest from, and nearest to their own goal line, which corresponded to the forward and back lines, respectively. Similarly, the vertical line-forces of each team were computed by averaging the mean lateral coordinates of the players furthest to the left and to the right on the pitch, corresponding to the left and right lines, respectively. Due to the small number of players participating in the SSCGs, only the wing lines and attacking and defending sectors were analyzed. Hence, the time series of the distances between forward-back and left-right lines of opposing teams were calculated according to team sectors, as follows: (i) dtH1 - distance between the back line of the underloaded team and the forward line of the overloaded team; (ii) dtH2 - distance between the forward line of the underloaded team and the back line of the overloaded team; (iii) dtV1 - distance between the left line of the overloaded team and the right line of the underloaded team; and (iv), dtV2 - distance between the right line of the overloaded team and the left line of the underloaded team.

All variables used in this study capture the interpersonal coordination tendencies at different levels of system analysis (inter-individual, intra- and inter-team coordination levels), as illustrated in Figure 13.

6.2.4 Statistical procedures

Mean ± standard deviations values of the ellipse areas were calculated for the numerically overloaded and underloaded teams according to skill level and different numerical relations. Given that the performance data of each team were analyzed separately and that there was a small number of participants per team (5 players in the overloaded team and 5, 4 and 3 players in the underloaded team), no inferential statistics were used to analyze major ranges areas.

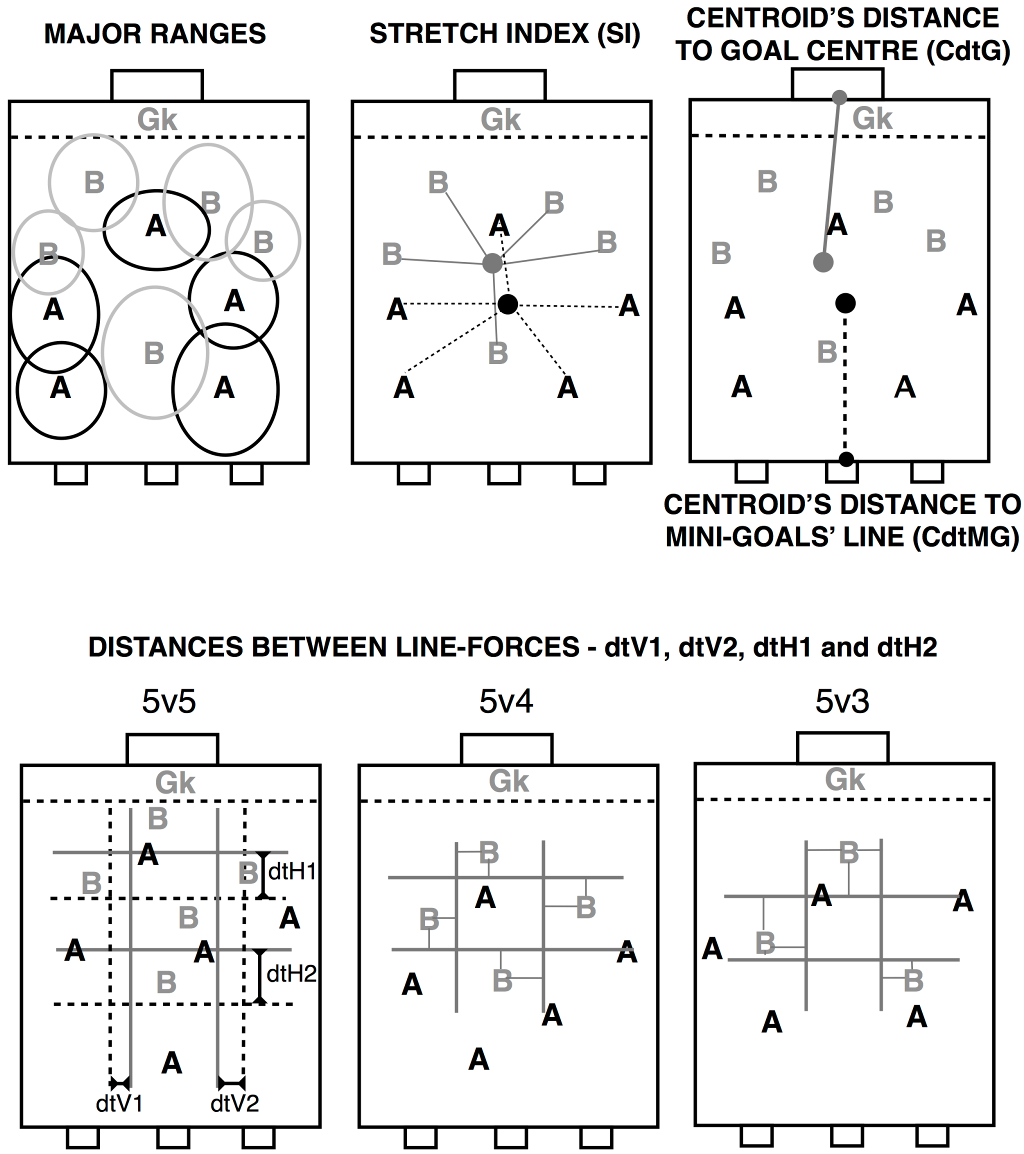

Figure 13 – Illustration of inter-individual (major ranges), intra- (stretch index and centroids' distance to goals) and inter-team (distances between line-forces) variables used. The lower left panel illustrates the distances between opposing horizontal (dtH1 and dtH2) and vertical line-forces (dtV1 and dtV2) in the 5v5 condition. The lower middle and right panels illustrate the calculation of horizontal and vertical line-forces in the underloaded team with 4 and 3 players, respectively. All fields used were 47.3 x 30.6 m (length x width). The overloaded team attacked the goal with a goalkeeper and the underloaded team attacked the mini-goals.

The time series values of intra- (SI, CdtMG and CdtG) and inter-team (dtH1, dtH2, dtV1 and dtV2) variables were compared statistically through analysis of variance methods. Given that these time series are of a stochastic nature, the successive measures were only partly determined by previous values. Hence, the assumption of independence of the observations required to run the ANOVAs was overcome by sampling uncorrelated data points. To this effect, for each variable, time series values interspersed with a time interval (*t*) were selected to ensure that each observation recorded would be uncorrelated with previous selected values. Thus, the time series were fitted to autoregressive models (AR) of various orders (1 to 10) with the argument that, if the data came from an AR(*p*) process, then $t \geq p$. Thus, *t* can be estimated by solving the first *p* Yule-Walker equations with correlations estimated using the sample autocorrelation coefficients. The order of the process is, then, estimated to minimize the Schwarz's Bayesian criterion that represents a trade-off between the fit of the AR model and the number of parameters estimated (Chatfield, 2003). Through the AR processes, 82% of the estimates were equal to p=4 and lower. Based on this finding, measures of all intra- and inter-team variables were sampled at every 4 seconds of play (totaling 90 independent measures per variable). After this procedure, for each SSCG and group, we obtained a set of independent game situations containing identical variances, means and standard deviations of the original variables' time series.

Two-way ANOVAs were then conducted to examine the effect of skill (2 levels: NLP and RLP) and numerical relations (3 levels: 5v5, 5v4 and 5v3) on each intra- and inter-team variable. Statistical analysis of intra-team variables was run separately, according to the teams' numerical advantage – overloaded and underloaded teams. Given the large sample of data points analyzed (540 data points per variable), all statistical comparisons reported outcomes below the conventional statistical significance alpha value of P=0.05. Thus, we focused on the magnitude of the effects (here reported as partial eta squared - η^2) obtained with the ANOVAs, following Cohen's guidelines (1988): (i) $0.01 \leq \eta^2 < 0.06$ – small effect; (ii) $0.06 \leq \eta^2 < 0.14$ – moderate effect; and (iii) $\eta^2 \geq 0.14$ – large effect. Bonferroni post-hoc pairwise comparisons and interaction effects were implemented when moderate or large effects of η^2 were identified.

For simplicity, when playing with equal number of players, the team attacking the goal with a goalkeeper and the team attacking the mini-goals were also denominated as overloaded and underloaded teams, respectively.

6.3 Results

6.3.1 Inter-individual coordination (major ranges)

Figure 14 illustrates the major ranges and means ± standard deviations of the ellipse areas in each treatment for each group of players.

The ellipse areas of the RLP were more superimposed, displaying different shapes, compared to the NLP skill level. The latter displayed ellipses that were more rationally distributed according to corridors (left and right) and sectors (forward and back), presenting rounded shapes. Analysis of the distribution of players' movement coordinates in the x- (longitudinal) and y-axis (lateral) in Figures 15 and 16 confirm that NLP displayed differentiated distributions in the x-axis (Figure 15). In contrast, the RLP tended to play on very similar longitudinal coordinates of the field, only varying their positioning along the y-axis (Figure 16). The RLP also presented broader distributions along the x-axis, which caused their ellipses to be oval-shaped.

Additionally, the mean areas of ellipses in the NLP group presented a similar trend for both the overloaded and underloaded teams in the 5v5 and 5v4 condition (see Figure 17). In the 5v3 condition, both teams increased their mean areas but with the underloaded team displaying much larger mean ellipse areas than the overloaded team. This was evident in the ellipses of two out of the three players and also in the distribution of their coordinates in the y-axis (Figure 15) that was broader in the 5v3 treatment.

Table 5 – ANOVA effect sizes.

Variables	Skill level (SL)	Numerical relation (NR)	SL x NR
SI	Overloaded: η^2=0.12*; Underloaded: η^2=0.16**	Overloaded: η^2=0.001; Underloaded: η^2=0.07*	Overloaded: η^2=0.02; Underloaded: η^2=0.005
CdtMG	η^2=0.04	η^2=0.16**	η^2=0.02
CdtG	η^2=0.01	η^2=0.14**	η^2=0.02
dtH1	η^2=0.001	η^2=0.02	η^2=0.05
dtH2	η^2=0.01	η^2=0.07*	η^2=0.02
dtV1	η^2=0.004	η^2=0.09*	η^2<0.001
dtV2	η^2=0.06*	η^2=0.01	η^2=0.002

Main effects of skill level and numerical relation and interaction effects of skill level x numerical relation on: (1) stretch index (SI); (2) centroid's distance to mini goals line (CdtMG); (3) centroid's distance to goal (CdtG); (4) horizontal lines' distances (dtH1 and dtH2) and (5) vertical lines' distances (dtV1 and dtV2). * Moderate effect; ** Large effect

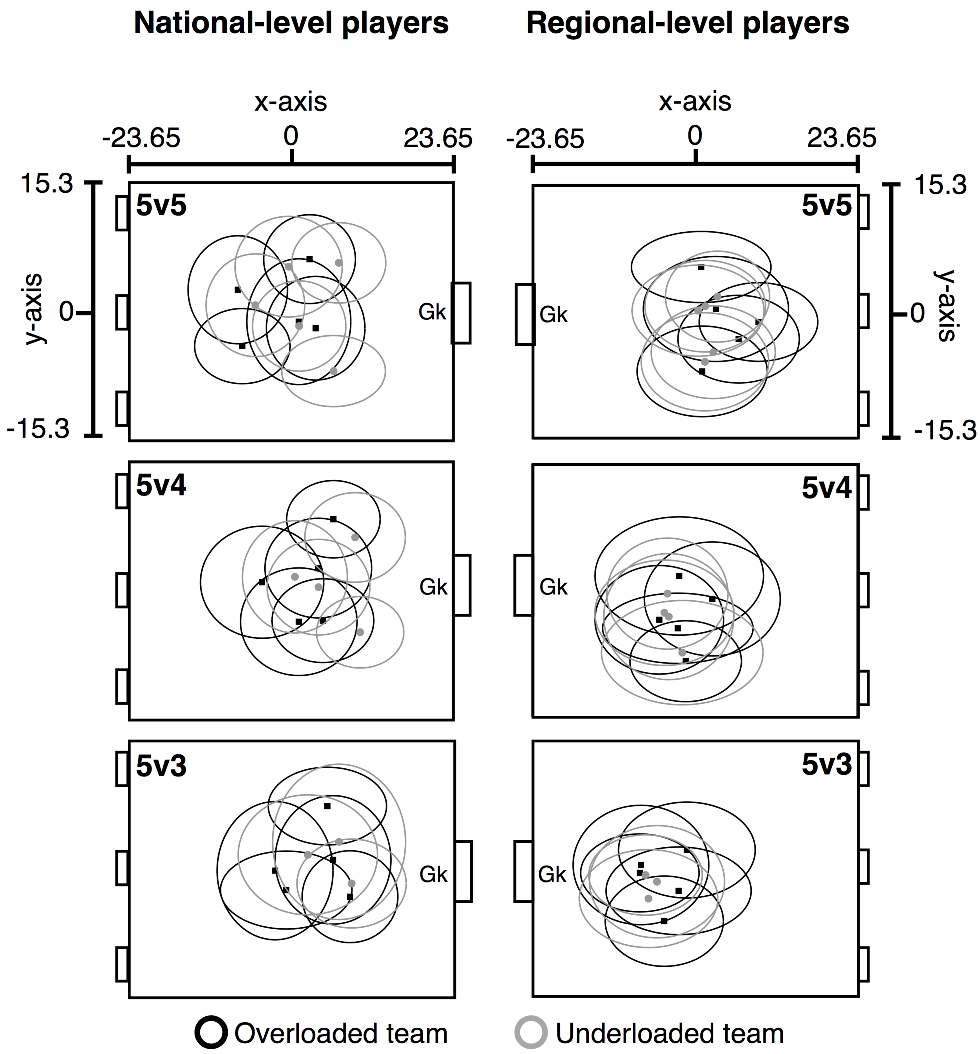

Figure 14 – Major ranges of national- (NLP) and regional-level players (RLP) in each SSCG. Black and grey ellipses depict the major ranges of the overloaded and underloaded teams, respectively. Overloaded teams attack the goal defended by a goalkeeper. Lateral (y-axis) and longitudinal (x-axis) depict field coordinates.

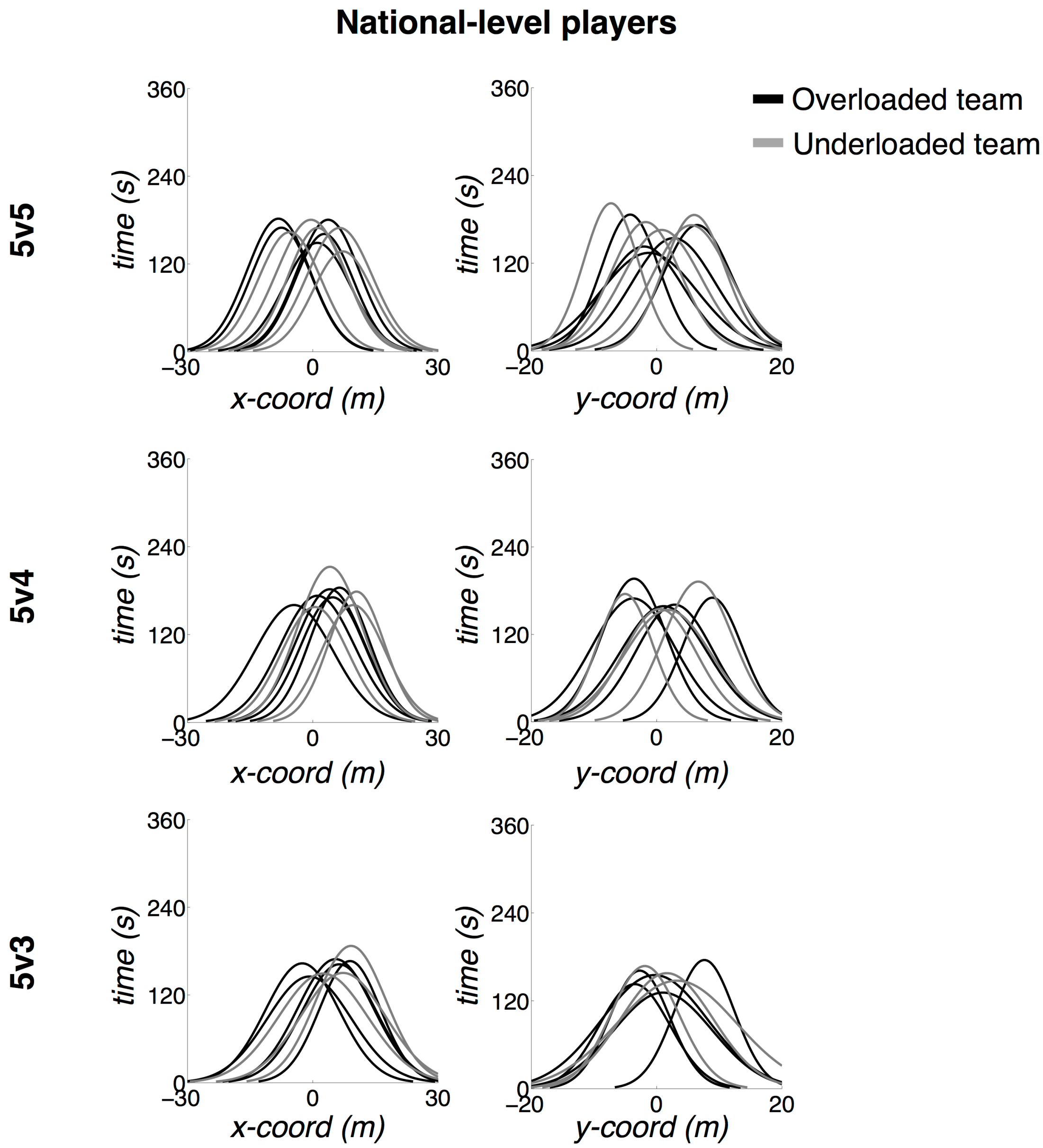

Figure 15 – Normal density function of the players' distribution along the x- (longitudinal) and y-axes (lateral) – national-level players (NLP) distribution. Field coordinates vary between -23.65 – 23.65 and -15.3 – 15.3 for the x- and y-axes, respectively. The origin (0, 0) corresponds to the field center.

The RLP group displayed different mean areas across treatments for both teams, but identical mean areas for both underloaded and overloaded teams. The larger mean areas were registered in the 5v4 treatment.

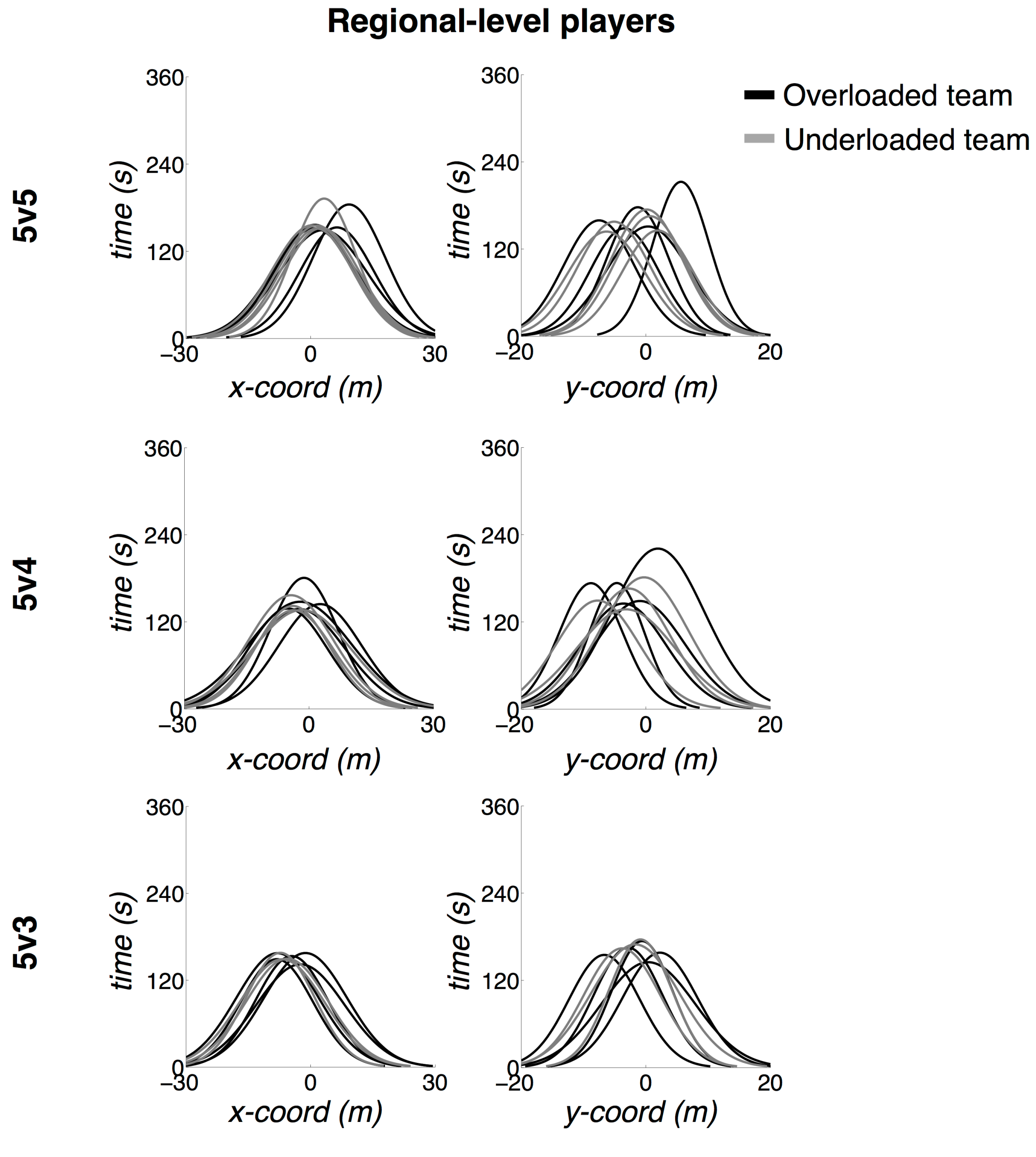

Figure 16 – Normal density function of the players' distribution along the x- (longitudinal) and y-axes (lateral) – regional-level players (RLP) distribution. Field coordinates vary between -23.65 – 23.65 and -15.3 – 15.3 for the x- and y-axes, respectively. The origin (0, 0) corresponds to the field center.

6.3.2 Intra-team coordination (stretch index and centroids' distance to own goal and mini-goals' line)

Statistical analysis of SI showed a moderate effect of skill for the overloaded team, $F(1,534)=71.759$, $P<0.001$, $\eta^2=0.12$. Higher mean values of

SI were found for NLP (*M*=8.58, *SE*=0.19) than RLP (*M*=7, *SE*=0.19, see Figure 18, left panel). No significant effects were observed for numerical relations, or the interactions (Table 5).

ANOVA of SI for the underloaded team presented a large effect of skill level, $F(1,534)=101.23$, $P<0.001$, $\eta^2=0.16$, revealing higher mean values of SI for NLP (*M*=7.99, *SE*=0.21) than RLP (*M*=5.86, *SE*=0.21). Analysis of SI in the underloaded team also revealed a moderate effect of numerical relations, $F(2,534)=19.66$, $P<0.001$, $\eta^2=0.07$. Bonferroni post hoc anallyses showed higher mean values of SI for 5v5 (*M*=7.85, *SE*=0.26), than for 5v4 (*M*=6.62, *SE*=0.26, *P*<0.001) and 5v3 (*M*=6.31, *SE*=0.26, *P*<0.001). Interaction effects were negligible (see Table 5).

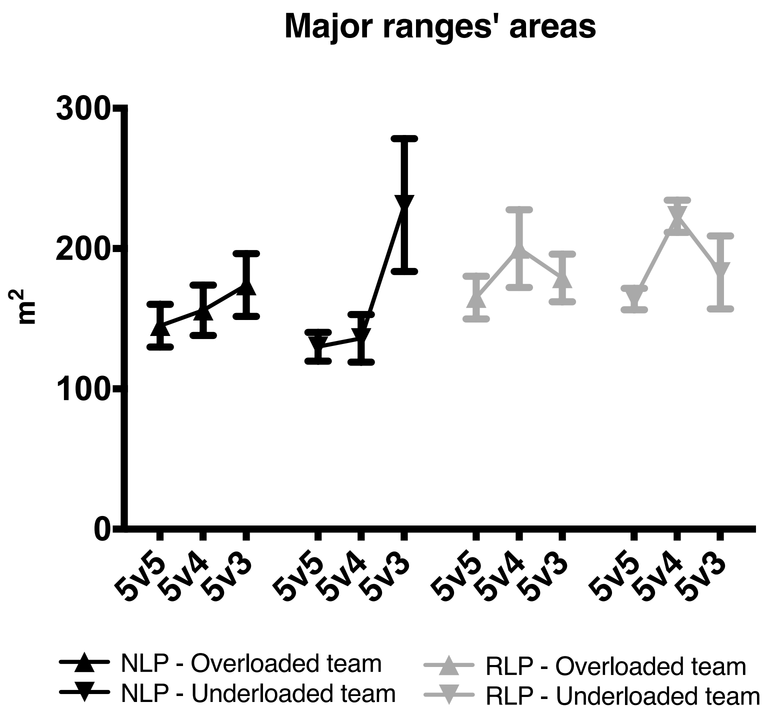

Figure 17 – Major ranges areas of national- (NLP) and regional-level players (RLP) in each treatment. Error bars represent the standard error of the mean.

Concerning CdtMG, ANOVA revealed a large effect of numerical relations, $F(2,534)=50.26$, $P<0.001$, $\eta^2=0.16$. Lower CdtMG mean values were found for 5v5 treatments (*M*=20.85, *SE*=0.86) than for 5v4 (*M*=27.13, *SE*=0.86, *P*<0.001) and 5v3 (*M*=29.15, *SE*=0.86, *P*<0.001, see Figure 18, right panel). Skill level and interaction effects were not statistically significant (Table 5).

Concerning the CdtG of the underloaded team, a large effect was also obtained for numerical relations, *F*(2,534)=43.65, *P*<0.001, η^2=0.14, with larger mean values displayed for 5v5 (*M*=26.19, *SE*=0.81) than for 5v4 (*M*=21.05, *SE*=0.81, *P*<0.001) and 5v3 (*M*=18.78, *SE*=0.81, *P*<0.001). Differences between 5v4 and 5v3 treatments were also observed (*P*=0.01, *SE*=0.81, see Figure 18, right panel). No significant effects of skill level and interactions were observed.

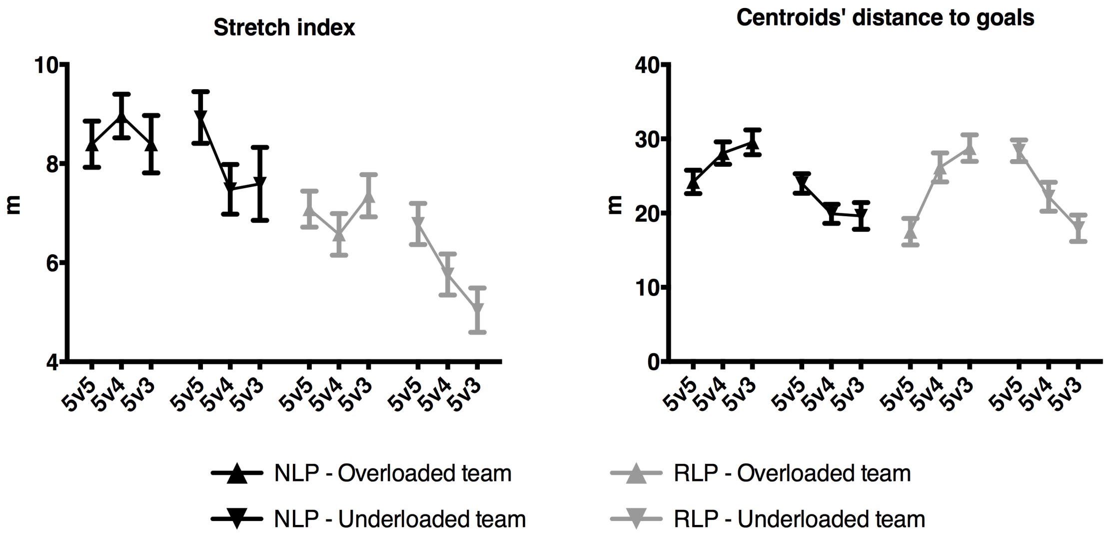

Figure 18 – Mean stretch index (SI) and centroids' distance to goals' center (CdtG) and mini-goals line (CdtMG) of overloaded and underloaded teams across treatments and expertise groups. Error bars represent the standard error of the mean.

6.3.3 Inter-team coordination (distances between opposing vertical and horizontal line-forces)

Despite not being sufficiently large to be conventionally considered a significant statistical effect, it is worth noting the interaction effect emerging for skill level and numerical relations, for confrontation of horizontal lines dtH1, *F*(2,534)=14.17, *P*<0.001, η^2=0.05, since it may have some practical significance (see discussion). Post-hoc analysis showed higher mean values of dtH1 for NLP (*M*=3.89, *SE*=0.32) than for RLP (*M*=2.82, *SE*=0.32, *P*<0.001) in the 5v5 treatment (Figure 19, left panel). In contrast, in the 5v3, post hoc analysis reported lower mean values of dtH1 for NLP (M=2.05, SE=0.32) than RLP (M=3.3, SE=0.32, P<0.001). No differences were found between groups in the 5v4 treatment (P=0.07).

Concerning dtH2, a moderate effect of numerical relation was observed, independent of skill level, $F(2,534)=20.19$, $P<0.001$, $\eta^2=0.07$. Post-hoc analysis showed lower mean values of dtH2 in the 5v5 (M=4.02, SE=0.34) than in the 5v4 (M=5.02, SE=0.39, P=0.01), and in the 5v3 (M=6.17, SE=0.34, P<0.001). Significant differences were also found between the 5v4 and 5v3 treatments (P=0.002).

Analysis of variance of dtV1 also registered a moderate effect for numerical relations, independent of skill level, $F(2,534)=25.22$, $P<0.001$, $\eta^2=0.09$, but small effects for skill level and interactions (Table 5). Post-hoc tests revealed higher mean values of dtV1 for 5v3 (M=4.2, SE=0.25) than for 5v4 (M=2.97, SE=0.25, P<0.001) and 5v5 (M=2.47, SE=0.25, P<0.001, see Figure 19, right panel).

The ANOVA of dtV2 revealed a moderate effect for skill level, $F(1,534)=33.4$, $P<0.001$, $\eta^2=0.06$, with larger mean values observed in the NLP (M=3.46, SE=0.19), compared to the RLP group (M=2.36, SE=0.19).

6.4 Discussion

In this study we adopted an ecological dynamics perspective to investigate how players in football teams, here viewed as multi-agent neurobiological systems, co-adapted performance behaviors (by swarming) to the imposition of distinct numerical relations during SSCGs. Values of inter-individual (major ranges), intra- (stretch index and centroids' distance to goals) and inter-team (distance between horizontal and vertical line-forces) coordination patterns were analyzed during performance in SSCGs played under different numerical relations (5v5, 5v4 and 5v3). Additionally, differences in skill level were observed, between national- and regional-level players, to understand how skill level interacted with numerical relational constraints.

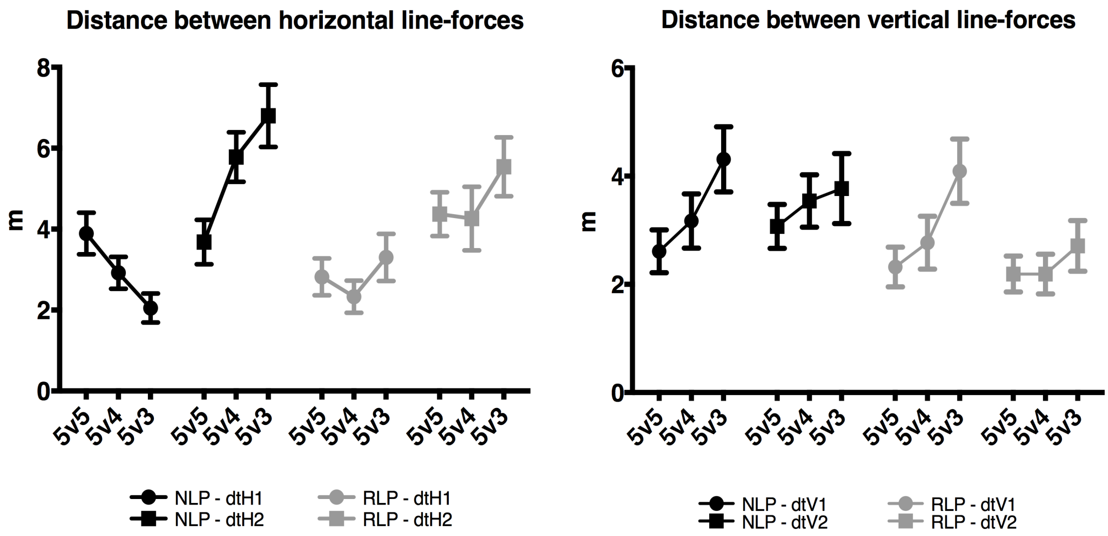

Figure 19 – Mean distances between horizontal (upper panels – dtH1 and dtH2) and vertical lines (lower panels – dtV1 and dtV2) across treatments and expertise groups. Error bars represent the standard error of the mean.

6.4.1 Inter-individual coordination within the team

The lower superimposition of the NLP ellipses (see Figures 14 and 15) reflected a more balanced occupation of different sections of the field, a basic principle required for successful performance in invasion team sports (Teodorescu, 1977). This process was not as clear in the RLP group whose major range tendencies reflected a poorer division of labor according to specific zones of the field (Duarte et al., 2012).

Analysis of ellipse shapes also supported the assumption that the NLP participants were more tactically balanced. Their rounded shapes reflected the similarity of movement amplitudes in the longitudinal and lateral direction. In contrast, RLP participants tended to present larger movement amplitudes in the longitudinal direction, as specified by the oval-shaped ellipses displayed and also by the distribution of their movements in the longitudinal axis in all treatments (see Figure 16). Considering the fact that, in general, they also possessed wider major ranges areas, it seems that these players performed more runs in the longitudinal direction than in the lateral plane. Clearly, skill level constrained the perception of different action possibilities for each group and the distinct interaction possibilities captured by the division of positional roles on field (i.e., distinct shared affordances).

In the 5v3 treatment the NLP underloaded team presented a considerable larger mean area than the overloaded team. In fact, this was the largest mean ellipse area of all treatments and groups. This outcome can be interpreted as the capacity of NLP participants to cover a wider playing area when playing under a strong numerical disadvantage (with two players less than the opposition). Indeed, when playing against a numerical disadvantage of only one player (5v4), the areas covered were similar to when they played in a numerical balance. This finding implies that for the NLP group, a numerical difference of only one player was not enough to change the players' interpersonal coordination tendencies, probably due to their superior capacity of working together to compensate for the missing player. The larger mean ellipse areas observed in the NLP overloaded team during the 5v3 treatment might be related to the fact that more free space was available to be exploited since the opposing team had two fewer players.

Concerning the RLP group, it is not clear why these players displayed larger mean ellipses areas in the 5v4 and not in the 5v3 treatments and more research is needed to clarify understanding of this effect.

In general, results on inter-individual coordination tendencies suggested that skill level was determinant in the perception of different possibilities for action and in constraining decisions (Silva et al., in press) emerging from each group of participants regarding their division of labor on field, here represented by distinct movement patterns and territorial occupation.

6.4.2 Intra-team coordination

The NLP group presented larger dispersion values than the RLP group in all treatments and teams (overloaded and underloaded team) and thus, a tendency to play in a more stretched way. However, playing against one or two fewer players did not provoke any significant changes in the dispersion values of both groups' overloaded teams.

The underloaded team of the NLP played in a more stretched way than the RLP team, perhaps reflecting their ability to spread out and cover the width of the field, when playing with a numerical disadvantage. In fact, during the defensive phase it is important that the defending team contracts to close down space near the ball but covering, at the same time, potential openings for the oppositions' passing lines. This observation signifies that players need to be spread out enough to be adjacent to different ball trajectories, according to the attackers' positions. Our findings concurred with data reported by Travassos, Araújo, Davids, et al. (2012). They showed that in non-intercepted passes in futsal, the distance of the second defender to the ball carrier decreased while the distance to the ball trajectory increased. In this sense, players can defend more efficiently if they are able to cover and press most of the possible passing lines available for an opponent, which implies that they should not be excessively contracted as a coordinating unit. By continually readjusting their positioning, based on defensive action possibilities for themselves and for teammates (e.g., covering space, closing passing lines, marking opponents, etc.), players can work to maintain the symmetry between competing teams in underloaded game contexts.

Nonetheless, in the underloaded teams, the values of SI decreased significantly across treatments, independent of skill level, signifying that the teams of both groups tended to contract when they were reduced in number. This finding was likely due to the fact that they spent more time performing defensive actions when underloaded. The NLP, however, presented similar dispersion values when playing with one and two players fewer, while the RLP group teams always tended to contract every time one player was omitted. Following the previous results of inter-individual coordination it seems plausible that this team maintained similar dispersion values through enlargement of their players' dominant regions. Thus, the same collective behavioral patterns were secured by distinct interpersonal coordination modes. This is another important characteristic of biological systems – the ability to degenerate behavior to satisfy different ecological constraints (Edelman & Gally, 2001).

Concerning the teams' relative positioning on field (depicted by the centroid distance to the goal line), results showed that, as the numerical difference between teams increased, the overloaded team players moved further away from their mini-goals and approached the underloaded team's goal. This behavior was evident for both groups. In contrast, underloaded team players tended to be attracted backwards on field to defend their goal. Thus, the overloaded teams managed to acquire space near the opposing team's goal and forced them to move backwards. This result is in accordance with data reported in the study of Travassos, Araújo, Duarte, et al. (2012) in 5v4+Gk performance contexts in futsal. This coordination tendency was evident when underloaded teams were reduced by one player, while presenting similar CdtMG and CdtG values in the 5v4 and 5v3 treatments. These findings indicated the conditions that facilitated multi-agent collectives to act in a collectively coordinated manner, once players had become attuned to information from their opponents' actions.

Synthesizing these main findings, the manipulation of numerical asymmetries on field during training tasks influenced the dispersion values of the teams being underloaded and the relative positioning of both teams on field. Overloaded teams tended to advance on field when opponents lost players, but without impacting in their dispersion values. In contrast, underloaded teams tended to retreat nearer to their own goal and contract in order to protect it. In both situations, the data suggested that players were collectively attuned to shared affordances. Playing with fewer players might have offered fewer opportunities to keep possession of the ball and possibly constrained the emergence of a more compact defensive block. In contrast, playing with more players probably offered more possibilities for maintaining possession and attacking the opposition goal (which is typically the main performance behavior intended to be promoted through the creation of overloads). Skill level seemed most influential on the way each group of players spread out on field during play, although both groups presented similar trends in their emergent behaviors.

6.4.3 Inter-team coordination

With regards to the distances between horizontal line-forces, results showed that the NLP participants reduced the distance value dtH1 (i.e., distance between the back line of the underloaded team and the forward line of the overloaded team) as the numerical difference between both teams increased. The opposite effect emerged for the distance value of dtH2 (i.e., distance between the forward line of the underloaded team and the back line of the overloaded team).

By forcing an approach to the underloaded team’s back line the NLP participants could have provoked the emergence of critical regions of performance where the balance between the opposing line-forces could be perturbed leading the social neurobiological system to other performance outcomes like the creation of goal scoring opportunities. Critical regions of performance are characterized by low values of interpersonal distances between attackers and defenders that can lead to transitions in system organisational states, with eventual consequences for performance outcomes (Passos et al., 2013) as previously observed in studies of performance in several other team sports (Araújo et al., 2004; Davids et al., 2006; Passos et al., 2008; Passos, Araujo, et al., 2009). In our study, the proximity of the confronting line-forces could also have led to the emergence of critical states, an assumption that needs to be scrutinized in future studies.

On the other hand, the increase in the distance of dtH2 in both groups across SSCGs was attributed to the fact that the underloaded team, because of the numerical disadvantage, prioritized the closing of space near its goal by moving their lines backwards. This result corroborates previous findings regarding behaviors related to the CdtG, and is in accordance with data from previous work by Travassos, Araújo, Duarte, et al. (2012).

The same trend for dtH1 was not so clear in the RLP participants, since the mean distance values of both variables were roughly approximate in the 5v5 and 5v4 treatments, and increasing in the 5v3 treatment. Apparently, the players at that skill level did not press the underloaded team back line when they were in numerical disadvantage. In fact, the opposite occurred in the 5v3 treatment.

With respect to vertical lines, both groups displayed identical values for dtV1 (i.e., the distance between the left line of the overloaded team and the right line of the underloaded team), which increased with numerical differences between teams. On the opposite wing (i.e., dtV2 or the distance between the right line of the overloaded team and the left line of the underloaded team), the space between lines remained relatively constant across SSCGs conditions for both skill groups. This finding signifies that teams maintained relatively the same distances between vertical line-forces across treatments on only one of the two wings of the field. This outcome might have been constrained by other possible factors besides numerical relations, like the players' preferred foot and strategic options.

In sum, the most important effects were registered in the proximity between an overloaded team's attacking line and an underloaded team's defensive line, only in the NLP group. This outcome may have evidenced exploratory performance behaviors of an overloaded team when offensively pressing the reduced number of players in an underloaded team in order to disturb the equilibrium of opposing line-forces to create scoring opportunities. This type of exploratory activity may have emerged in the more skilled group perhaps due to their better technical skills and the capacity to dribble past opponents at critical values of interpersonal distances (see Duarte et al., 2010, for evidence on critical values of interpersonal distances between attacker-defender dyads in promoting dribbling actions).

6.5 Conclusions

Data from this study shed important insights on co-adaptive behaviors of agents in team sport systems performing under specific task constraints afforded by different numerical relations and skill levels in SSCGs (see Table 6 for a synthesis of main findings). Individual and team coordination tendencies were clearly constrained by the numerical relations between competing teams and the players' skill level. Skill levels provided different action possibilities available to synergistic groups of players, highlighting the importance of adapting training tasks to the players' individual characteristics in order to facilitate the emergence of required team behaviors. Accordingly, the findings of this study support the assumption that teams, here conceptualized as swarming neurobiological superorganisms, possess the ability to co-adapt to performance constraints that can be manipulated by practitioners during practice in SSCGs. Therefore, designing *shared affordances* for specific group tactics to emerge during practice through manipulations of numerical relations seems a feasible pedagogical methodology. In this study we identified the emergent behaviors constrained by different numerical relations in collective systems, which need to be considered when seeking to enhance the acquisition of specific skills and team tactical behaviors during training.

Future studies should identify the specific *affordances* supporting such tactical behaviors in order to provide deeper understanding of the players' actions and tactical relations during SSCGs. This information is deemed crucial for coaches to regulate their instructions and feedback provided to players.

Table 6 – Synthesis of inter-individual, intra- and inter-team behavioral trends across SSCGs.

Dominant regions	**Teams' dispersion**	**Teams' relative positioning on field**	**Space between line-forces on wings**	**Space between line-forces on sectors**
Overloaded team players: increased; Underloaded team players: increased;	Overloaded team: maintained; Underloaded team: decreased.	Overloaded team: approached the opponent's goal; Underloaded team: approached own goal.	dtV1: increased with numerical difference; dtV2: maintained across all numerical differences.	dtH1: decreased as the numerical difference increased for NLP; increased on 5v3 for RLP; dtH2: increased with the numerical difference.
Small-sided and conditioned games sequence: (i) 5v5 (ii) 5v4 and (iii) 5v3. National- and regional-level players displayed the same behavioral trends, except for dtH1 (see table). Differences between groups were observed for the individual dominant regions, means of teams' dispersion and space between dtV2 line-forces.				

6.6 References

Araújo, D., Davids, K., Bennett, S., Button, C., & Chapman, G. (2004). Emergence of sport skills under constraints. In M. Williams & N. Hodges (Eds.), *Skill Acquisition in Sport Research, Theory and Practice* (pp. 409-433). UK: Routledge.

Araújo, D., Silva, P., & Davids, K. (in press). Capturing group tactical behaviors in expert team players. In J. Baker & D. Farrow (Eds.), *Rotledge Handbook of Sport Expertise*: Routledge.

Button, C., Chow, J.-Y., Travassos, B., Vilar, L., Duarte, R., Passos, P., Araújo, D., & Davids, K. (2012). A nonlinear pedagogy for sports teams as social neurobiological systems: how teams can harness self-organization tendencies. In A. Ovens, T. Hopper & J. Butler (Eds.), *Complexity thinking in physical education* (pp. 135-150). Oxon: Routledge.

Chatfield, C. (2003). *The analysis of time series: an introduction.* (Sixth ed.). New York: Chapman & Hall.

Chow, J. Y., Davids, K., hristovski, R., Araújo, D., & Passos, P. (2011). Nonlinear pedagogy: learning design for self-organizing neurobiological systems. *New Ideas in Psychology, 29*(2011), 189-200.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science & Medicine in Sport, 13*(1), 133-135.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews, 41*(3), 154-161.

Davids, K., Button, C., Araújo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human movement studies. *Adaptive Behavior, 14*, 73-94.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sport teams as superorganisms: implications of biological models for research and practice in team sports performance analysis. *Sports Medicine, 42*(8), 633-642.

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., & Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *Journal of Systems Science and Complexity, 26*, 62-72.

Duarte, R., Araújo, D., Gazimba, V., Fernandes, O., Folgado, H., Marmeleira, J., & Davids, K. (2010). The ecological dynamics of 1v1 sub-phases in association football. *The Open Sports Sciences Journal, 3*, 16-18.

Duarte, R., Fernandes, O., Folgado, H., & Araújo, D. (2013). Single camera analysis in studying pattern forming dynamics of player interactions in team sports. In K. Davids, D. Araújo, N. Balague, C. Button & P. Passos (Eds.), *Complex systems in sport*: Routledge.

Eccles, D. (2010). The coordination of labour in sports teams. *International Review of Sport and Exercise Psychology, 3*(2), 154-170.

Edelman, G., & Gally, J. (2001). Degeneracy and complexity in biological systems. *Proceedings of the National Academy of Sciences of the United States of America, 20*(24), 13763-13713-13768.

Fonseca, S., Milho, J., Travassos, B., & Araújo, D. (2012). Spatial dynamics of team sports exposed by Voronoi diagrams. *Human Movement Science, 31*(6), 1652-1659.

Frencken, W., Lemmink, K., Delleman, N., & Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science, 11*(4), 215-223.

Gibson, J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Gréhaigne, J.-F. (1988). Game systems in soccer from the point of view of coverage of space. In T. Reilly, A. Lees, K. Davids & W. J. Murphy (Eds.), *Science and Football* (pp. 316-321). London: E. & FN Spon.

Gréhaigne, J.-F., Bouthier, D., & David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *Journal of Sports Sciences, 15*(2), 137-149.

Grehaigne, J.-F., & Godbout, P. (1995). Tactical knowledge in team sports from a constructivist and cognitivist perspective. *Quest, 47*(4), 490-505.

Hristovski, R., Davids, K., Araújo, D., & Passos, P. (2011). Constraints-induced emergence of functional novelty in complex neurobiological systems: a basis for creativity in sport. *Nonlinear Dynamics, Psychology, and Life Sciences, 15*(2), 175-206.

Hughes, C. (1994). *The football association coaching book of soccer tactics and skills*. Harpenden: Queen Anne Press.

Johnston, R., Watsford, M., Pine, M., Spurrs, R., & Sporri, D. (2013). Assessment of 5 Hz and 10 Hz GPS units for measuring athlete movement demands. *International Journal of Performance Analysis in Sport, 13*, 262-274.

Kesebir, S. (2012). The Superorganism Account of Human Sociality: How and When Human Groups Are Like Beehives. *Personality and Social Psychology Review, 16*(3), 233-261.

Mark, L. S. (2007). Perceiving the Actions of Other People. *Ecological Psychology, 19*(2), 107-136.

Marsh, K. L., Richardson, M. J., & Baron, R. M. (2006). Contrasting approaches to perceiving and acting with others. *Ecological Psychology, 18*(1), 1-38.

Passos, P., Araújo, D., & Davids, K. (2013). Self-Organization Processes in Field-Invasion Team Sports. *Sports Medicine, 43*(1), 1-7.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Milho, J., & Serpa, S. (2008). Information-governing dynamics of attacker-defender interactions in youth Rugby Union. *Journal of Sports Sciences, 26*(13), 1421-1429.

Passos, P., Araújo, D., Davids, K., Gouveia, L., Serpa, S., & Milho, J. (2009). Interpersonal pattern dynamics and adaptative behavior in multiagent neurobiological systems: conceptual model and data. *Journal of Motor Behavior, 41*(5), 445-459.

Passos, P., Araujo, D., Davids, K., Gouveia, L., Serpa, S., Milho, J., & Fonseca, S. (2009). Interpersonal Pattern Dynamics and Adaptive Behavior in Multiagent Neurobiological Systems: Conceptual Model and Data. *Journal of Motor Behavior, 41*(5), 445-459.

Passos, P., Milho, J., Fonseca, S., Borges, J., Araujo, D., & Davids, K. (2011). Interpersonal Distance Regulates Functional Grouping Tendencies of Agents in Team Sports. *Journal of Motor Behavior, 43*(2), 155-163.

Rampinini, E., Impellizzeri, F. M., Castagna, C., Abt, G., Chamari, K., Sassi, A., & Marcora, S. M. (2007). Factors influencing physiological responses to small-sided soccer games. *Journal of Sports Sciences, 25*(6), 659-666.

Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R. L., & Schmidt, R. C. (2007). Rocking together: dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science, 26*, 867-891.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Schmidt, R., & Richardson, M. (2008). Dynamics of interpersonal coordination. In A. Fuchs & V. K. Jirsa (Eds.), *Coordination: Neural, Behavioral and Social Dynamics* (pp. 281-308). Verlag Berlin Heidelberg: Springer.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: Bodies and minds moving together. *Trends in Cognitive Sciences, 10*(2), 70-76.

Silva, P., Aguiar, P., Duarte, R., Davids, K., Araújo, D., & Garganta, J. (in press). Effects of pitch size and skill level on tactical behaviours of Association Football players during small-sided and conditioned games. *International Journal of Sports Science & Coaching*.

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*, 765-772.

Sinnott, R. W. (1984). Virtues of the Haversine. *Sky and Telescope, 68*(2), 159.

Stearns, S. (2007). Are we stalled part way through a major evolutionary transition from individual to group? *Evolution, 61*, 2275-2280.

Stoffregen, T., Gorday, K., & Sheng, Y.-Y. (1999). Perceiving affordances for another person's actions. *Journal of Experimental Psychology: Human Perception and Performance, 25*(1), 120-136.

Sumpter, D. J. T. (2006). The principles of collective animal behaviour. *Philosophical transactions of the Royal Society B: Biological Sciences, 361*(1465), 5-22.

Teodorescu, L. (1977). *Théorie et méthodologie des jeux sportifs*: Les éditeurs français réunis.

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychology of Sport & Exercise, 13*(2), 216-223.

Travassos, B., Araújo, D., Duarte, R., & McGarry, T. (2012). Spatiotemporal coordination behaviors in futsal (indoor football) are guided by informational game constraints. *Human Movement Science, 31*(4), 932-945.

Travassos, B., Araújo, D., Vilar, L., & McGarry, T. (2011). Interpersonal coordination and ball dynamics in futsal (indoor football). *Hum Mov Sci, 30*(6), 1245-1259.

Vilar, L., Araújo, D., Davids, K., & Bar-Yam, Y. (2013). Science of winning soccer: emergent pattern-forming dynamics in Association Football. *Journal of Systems Science and Complexity, 26*(1), 73-84.

Withagen, R., Poel, H. J. d., Araújo, D., & Pepping, G.-J. (2012). Affordances can invite behaviour: Reconsidering the relationship between affordances and agency. *New Ideas in Psychology, 30*, 250-258.

Witt, J. K., & Sugovic, M. (2012). Does ease to block a ball affect perceived ball speed? Examination of alternative hypotheses. *Journal of Experimental Psychology: Human Perception and Performance, 38*(5), 1202-1214.

Witt, J. K., Sugovic, M., & Taylor, J. E. T. (2012). Action-specific effects in a social context: Others' abilities influence perceived speed. *Journal of Experimental Psychology: Human Perception and Performance, 38*(3), 715-725.

Worthington, E. (1974). *Learning and teaching soccer skills*. Hollywood: Wilshire Book Company.

Yue, Z., Broich, H., Seifriz, F., & Mester, J. (2008). Mathematical analysis of a soccer game. Part I: individual and collective behaviours. *Studies in Applied Mathematics, 121*, 223-243.

Chapter 7

Effects of manipulations of player numbers vs. field dimensions on inter-individual coordination during small-sided games in youth football [11]

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Abstract

The relative space per player formulated in small-sided and conditioned games can be manipulated either by promoting variations in player numbers or by modifying field dimensions. In this study we analysed how the same relative spaces per player, obtained through manipulations of player numbers and field dimensions, influenced inter-individual coordination. The positional data (GPS, 10 Hz) of 24 U-15 yrs performing in three different relative spaces per player (118, 133 and 152m^2) was used. Inter-individual behavioural measures included: (i) effective relative space per player, (ii) radius of free movement; (iii) numerical relations inside each player's relative space per player; and (iv) players' spatial distribution variability. Magnitude-based inferences were used to analyse the practical significance of the selected variables. Results showed that manipulations of player numbers elicited more free space in the vicinity of each player. However, more advantageous numerical relations adjacent to each individual player and broader individual spatial distributions on field were observed during manipulations of field dimensions. These findings highlight the complex nature of performance behaviours captured by the co-adaptation of players to surrounding spatial constraints. Sport pedagogists should carefully evaluate the use of player numbers and field dimensions as strategies to simulate constraints of specific game contexts.

Keywords: co-adaptive behaviours, coordination tendencies, task constraints, GPS, soccer.

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[11] Silva, P., Esteves, P., Correia, V., Davids, K., Araújo, D. & Garganta. J. (2015). Effects of manipulations of player numbers vs. field dimensions on inter-individual coordination during small-sided games in youth football. *International Journal of Performance Analysis in Sport (in press).*

7.1 Introduction

Team sports like association football are considered complex systems where patterns of coordinated behaviour emerge under constraints of dynamically changing performance environments (Duarte et al., 2013; Passos et al., 2008). To understand coordination dynamics in social complex systems like team games it is mandatory to not just study the motion of each independent component (i.e. competing and cooperating players). Rather, coordination tendencies between team sports players emerge from spatiotemporal interactions between performers as they adapt to evolving performance constraints, such as opponents moving towards a scoring target (Duarte et al., 2012).

Recently, some studies have adopted a complex systems orientation to examine how manipulations of specific constraints in small-sided and conditioned gam[12] (SSCGs) influence interpersonal behaviours of performers (for a review see Davids et al., 2013). This recognition that SSCGs provide a viable opportunity to develop individual and collective performance behaviours requires more effort to capture the tactical coordination processes that emerge from interpersonal interactions of players and/or groups of players during performance in such practice tasks. Developing understanding in this area of work is crucial for designing effective practice simulations in team sports, since the co-adaptations of individual players reflect the tactical behaviours that occur under specific task constraints.

Within the context of SSCGs, the relative space per player (or individual playing area) – here considered as the total available field area divided by the number of players (Casamichana & Castellano, 2010) – might impact on performance behaviours (Fradua et al., 2013; Platt et al., 2001). Either by manipulating field dimensions or player numbers, changes in relative spaces per player demand continuous adaptations in co-positioning and co-

[12] Small-sided and conditioned games are commonly considered as modified games played on reduced pitch dimensions (small-sided), often using adapted rules and involving a smaller number of players than traditional games (representing manipulations of playing conditions) (Gabbett et al., 2009; Vilar et al., 2014). In team sports, they are considered to provide simulations of aspects of competitive performance environments which allow athletes to practice movement patterns and interactive tactical behaviours related to game phases like attacking and defending (Davids, et al., 2013).

orientation between attackers and defenders (Chow et al., 2006; Davids et al., 2013).

Recently, Fradua et al. (2013) attempted to determine optimal relative spaces per player for different formats of SSCGs, in view of the lack of solid evidence from studies in the field. The authors calculated the individual relative space per player by dividing the effective playing space (defined by the smallest rectangle encompassing all outfield players during competitive performance) by the twenty outfield players. With this information the investigators created SSCGs field dimensions that closely replicated this relative space per player in an attempt to recreate the same spatial-temporal interactions of football matches.

The rationale for continuous spatial adaptations between players is predicated on the use of evolving informational sources, related to their relative orientation to the ball, scoring target, teammates and opponents, to regulate their performance behaviours (Silva et al., 2013). These intertwined relations invite actions (Withagen et al., 2012). As such, they provide possibilities for acting in the game that sustain team coordination under the constraints of competitive performance environments (Silva, Travassos, et al., 2014). For instance, decreases in relative space per player constrain the spatial-temporal interactions established between competing players due to reduced time and space to act. Hence, the numerical relations between players in the vicinity of each individual's location on field might also be constrained by the size of the relative space per player. Reduced available space may inevitably decrease values of interpersonal distance and facilitate the creation of different relations between the number of opponents and number of teammates near the players' action zones (e.g., overloading). Such numerical relations are an important aspect that must be considered, given that they may change tactical performance during SSCG (Travassos et al., 2014, Silva, Travassos, et al., 2014). During regular competitive performance, changes in numerical dominance of a team (i.e., through overloading in specific sub-areas of play) has been revealed as crucial in the maintenance of defensive stability and the creation of offensive opportunities (Vilar et al., 2013).

Previous studies analysing the effects of field dimensions on tactical behaviours have reported different co-adaptations between players as a function of different relative space per players created in experiments. Silva, Aguiar, et al. (2014) observed broader movement trajectories of players during performance, measured through the entropy of their spatial distributions on field under constraints of smaller values in SSCG. Vilar et al. (2014) demonstrated that fewer opportunities to maintain ball possession occurred within smaller field dimensions. In another study, Frencken et al. (2013) observed significantly different inter-team lateral and longitudinal distance values arising from different individual relative space per player on shorter performance area dimensions, resulting in smaller values of inter-team distances. To the best of our knowledge, it is unknown whether changes in relative space per player obtained through manipulating player numbers would provide the same interpersonal adaptations in performance behaviours as manipulation of field dimensions.

The aim of this study was to extend knowledge on the functional utility of SSCGs in understanding how specific manipulations of field dimensions and player numbers constrained youth football players' performance behaviours. We specifically investigated how field dimensions and player numbers manipulations, replicating the same relative space per player, affected individual playing areas, distance to nearest opponents and numerical relations emerging in SSCGs using a team of under-15 yrs football players as participants. The regularity of the spatial distribution of players during performance was also analysed to verify how players reacted to more restricted or broader locations on field, by adapting to changes in surrounding information sources provided either by field dimensions and player numbers manipulations. Given that the existing literature on manipulations of relative space per player is sparse, we sought to evaluate insights from previous research, hypothesizing that the same values of relative space per player, promoted either by manipulations of player numbers or field dimension, would likewise constrain emergence of inter-individual performance-related behaviours.

7.2 Methods

7.2.1 Participants

Twenty-four players from an under-15 years football development squad (age: 14.5±0.53; height: 165.63±7.62; body mass: 55.68±7.27) competing at a regional-level (playing and training experience: 6.11±2.05 years) participated in this experiment. Their legal tutors provided written informed consent authorizing their participation in this study after being informed of the benefits and risks of the experiment. All procedures were in accordance with the ethical standards of the ethics committee from the Faculty of Sports of Porto University.

7.2.2 Task and procedures

SSCGs were designed to account for the same relative space per player, whether involving field dimensions or player numbers manipulations. Three relative spaces per player areas were considered for this experiment – 118, 133 and 152 m^2 (see Table 7). These areas have been calculated from a reference field dimension designed for a 6v6 game context – 57.3 x 37.1 m (length x width) that was obtained by reducing the width and length of an official football field – 105 x 68 m as a reference – in proportion to the number of players involved in a 6-a-side SSCG, as suggested in coaching literature (Hughes, 1994). The manipulation of players using a constant area of 57.3 x 37.1 m yielded 118, 133 and 152 m^2 relative space per player areas for 7v7, 8v8 and 9v9 game contexts, respectively. Then, the manipulation of field dimensions for a constant player numbers game context (i.e., 6v6) were calculated to match the same relative space per player areas of those from player numbers manipulations. Since different length per width relations of the fields could impact on the variables of this study (for instance, by promoting different shapes for the effective areas of play; see Silva, Duarte, et al., 2014), the same length per width ratio was maintained for all SCCGs. This ratio was the same of a regular football field (ratio: 1.54 – 105 x 68 m, as a reference).

Table 7 – Relative space per player (RSP) and small-sided games formats with manipulations of field dimensions (FD) and player numbers (PN). The same ratio of length per width was maintained in all SSCGs.

SSCGs Constraints	RSP - 152 m2	RSP - 133 m2	RSP - 118 m2
Field dimensions (Player numbers held constant)	6v6; 52.9 x 34.4 m (length x width)	6v6; 49.5 x 32.2 m (length x width)	6v6; 46.7 x 30.3 m (length x width)
Player numbers (Field dimensions held constant)	7v7 57.3 x 37.1 m (length x width)	8v8 57.3 x 37.1 m (length x width)	9v9 57.3 x 37.1 m (length x width)
Field Length x Width ratio	1.54	1.54	1.54

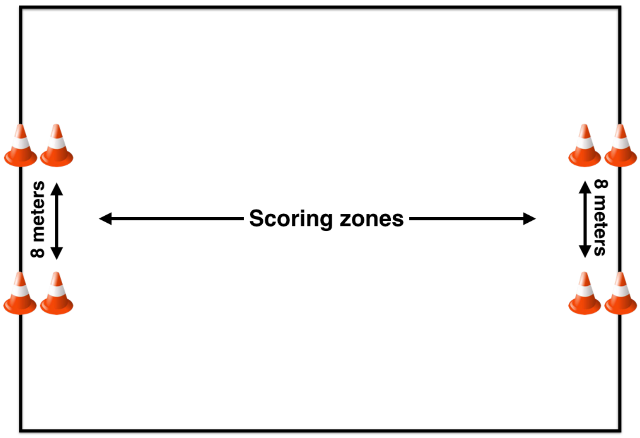

Figure 20 – Representation of the field and scoring zones.

Given that the main objective was to analyse how players managed different relative spaces per player, the SSCGs were played without goalkeepers to avoid the creation of spatial gaps between the former and the defensive line (Fradua et al., 2013). A natural attraction towards the central corridor promoted by the existence of goals was constrained by attributing points whenever a player crossed a scoring zone delimited with cones (separated by 8 m and centred on the opponent's team end line) with the ball under control (Figure 20). All trials were conducted according to the official rules of association football, with the exception of the offside rule, which was not applied.

In each treatment there were three matches of 6-mins duration, yielding a total of 18 games observed throughout a period of two weeks (6 days). All SSCGs were conducted prior to the start of the team's regular practices and after an initial standard warm-up of fifteen minutes comprising drills with a ball (individually and/or in pairs) followed by sprinting activities and stretching. Matches were randomly distributed across training sessions and a period of 4-minutes between exercise bouts was allowed to facilitate passive recovery and rehydration. During rest periods, players were allowed to drink fluids *ad libitum*. The order of the SSCGs was randomly set and only one trial per treatment was performed in each session, up to a maximum of three SSCGs per session (Table 8). Several balls were distributed around the experiment performance area in order to minimize trial stoppages. The players were instructed to not leave the performance area during the execution of the SSCGs to maximise observation time by the experimenters. During the SSCGs, neither the coaches nor the experimenters were allowed to provide instructions to players.

Table 8 – Distribution of the small-sided games across training sessions.

Week 1			**Week 2**		
Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
6v6 (118 m^2)	6v6 (133 m^2)	9v9 (118m^2)	6v6 (152 m^2)	7v7 (152 m^2)	6v6 (118 m^2)
8v8 (133 m^2)	9v9 (118 m^2)	6v6 (133 m^2)	8v8 (133 m^2)	9v9 (118 m^2)	8v8 (133 m^2)
6v6 (152 m^2)	7v7 (152 m^2)	7v7 (152 m^2)	6v6 (118 m^2)	6v6 (133 m^2)	6v6 (152 m^2)

7.2.3 Data collection

Each player wore a global positioning tracking device (Qstarz, Model: BT-Q1000eX) that recorded his 2D positional coordinates at a sampling frequency rate of 10 Hz. The reliability of similar type of devices has been well documented in the literature (Coutts & Duffield, 2010; Johnston et al., 2013). The performance area was calibrated with the coordinates of four GPS devices stationed in each corner for approximately four minutes. The absolute coordinates of each corner were calculated as the median of the recorded time series, providing measurements that were robust to typical fluctuations of GPS signals. These absolute positions were used to set the Cartesian coordinate systems for each performance area, with the origin placed at the performance area centre. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). Fluctuations in player positioning were reduced using a moving average filter with a time scale of 0.2 seconds. Data resampling was employed to synchronize the time series of all players within each trial.

7.2.4 Variables

Position data – longitudinal (x-) and latitudinal (y-) coordinates – obtained through the GPS system were used to calculate the: (i) effective relative space per player; (ii) radius of free movement; (iii) players' spatial distribution variability; and (iv), numerical relations established inside the individual relative space per player. The effective relative space per player was calculated according to the recommendations of Fradua et al. (2013). These authors proposed that the effective space allocated to each player should be calculated by dividing the area of the effective playing space delimited by the smallest rectangle encompassing all players, and not by dividing the total field area by the number of players. This quantity revealed the amount of free space, theoretically, that would be available for each player during each trial. In this study, however, for a more precise estimate of this variable, we calculated the polygonal area (m^2) defined by the players located at the periphery of play by computing the area of the smallest convex hull containing all players. For each SSCG this area was computed and divided by the number of players involved, second-by-second, yielding a total of 1083 measures per treatment (*n* = 6 minutes x 60 seconds x 3 trials per treatment).

The radius of free movement was defined as a measure of the degree of free movement without any opponents calculated in meters. For each player, the distance to his nearest opponent was quantified over time and averaged for statistical purposes. The spatial distribution variability was assessed by measuring the entropy of individual distribution maps (Shannon, 1948). These were calculated by discretizing the SSCG fields into bins and measuring the amount of time spent in each bin according to the sampling frequency of 10 Hz for the GPS acquisition system. The spatial distribution maps were normalized to total trial time, to produce spatial probability distributions (heat maps). The size of the bins was the same for all performance areas, which were chosen to satisfy an adequate balance between high spatial resolution and high range of measured values. A bin size of 1 m^2 was used allowing both sufficient spatial detail and large variability in the bin counting (>100×dt). For visualization purposes only, the heat maps were spatially filtered with a Gaussian kernel with a standard deviation of 1 (bin). Considering a performance area partition with N bins and setting p_i as the measured probability of finding the player in bin i, the entropy S of the spatial distribution is

$$S = -\sum_{i=1}^{N} p_i \log p_i \tag{1}$$

Normalized entropy was used to place the results within the range between 0 and 1, allowing for comparisons between different field dimensions.

$$S\% = \frac{1}{\log N} \sum_{i=1}^{N} p_i \log p_i \tag{2}$$

High (near 1) and low (near 0) entropy values were interpreted as irregular and regular spatial distribution variability, respectively. A more irregular spatial distribution was interpreted as facilitating broader tactical involvement of players (e.g., advancing up field to attack and retreating back to defend, or playing both on the left and right sides of the performance area in the same SSCG). A more regular spatial distribution was considered to represent a more restricted tactical role (e.g., playing most of the time in a defensive role).

Finally, the numerical relations in the vicinity of each player were computed as the difference between the number of teammates and the number of opponents. To our knowledge there are no consistent guidelines for determining a player's momentary action zone for which his actions could be considered to directly influence and be influenced by the movements and numerical relations established between nearest opponents and teammates. Therefore, we calculated the circular relative space per player area surrounding each player, point-by-point over time that corresponded to each SSCG (118, 133 or 152 m^2), since, in theory, it is considered to represent the performance area allocated to each player (Casamichana & Castellano, 2010; Hill-Haas et al., 2011). For statistical purposes, the proportion of time spent in each of the numerical relations found was calculated for each player in each trial. The numerical relations "NR(+1)" (plus one teammate), "NR(=)" (equal number of teammates and opponents), "NR(-1)" (minus one teammate), "NR(-2)" (minus two teammates) and "NR(free)" (relative space per player free of players – teammates and/or opponents) accounted for at least 95% of the time in all SSCG. Other numerical relations were disregarded given that the number of occurrences was not reasonably large to be considered.

7.2.5 Data analysis

The effective relative space per player, radius of free movement, spatial distribution variability and numerical relations were analysed for practical significance using magnitude-based inferences (Buchheit & Mendez-Villanueva, 2014; Hopkins et al., 2009). Within- and between-treatment effect sizes with 90% confidence intervals were calculated using pooled standard deviations. Threshold values for Cohen's effect sizes were >0.2 (small), >0.6 (moderate), and >1.2 (large) (Cohen, 1988). Probabilities were calculated to assess whether true effects obtained represented substantial changes (Batterham & Hopkins, 2005). The smallest standardised change for each variable was considered to be 0.2 multiplied by the between-subject standard deviation value, based on Cohen's effect size principle (Buchheit & Mendez-Villanueva, 2014). Quantitative probabilities of higher or lower differences were evaluated qualitatively as: < 1%, almost certainty not; 1-5% very unlikely; 5-25%, unlikely; 25-75%, possible; 75-95%, likely; 95-99%, very likely; > 99%, almost certain (Hopkins, 2002). If the probabilities of the effect being higher or lower than the smallest worthwhile difference were simultaneously > 5%, the effect was deemed unclear. Otherwise, the effect was clear and reported as the magnitude of the observed value.

7.3 Results

Figure 21 (upper left panel) shows standardised mean differences between manipulations of player numbers and field dimensions for the effective relative space per player, radius of free movement and spatial distribution variability. Descriptive statistics (mean ± standard deviation) of these quantities are summarized in Table 9. Differences can be observed for all variables and relative spaces per player treatments (118, 133 and 152 m^2). The effective relative space per player was larger for manipulations of player numbers with the largest difference being found in the smallest relative space per player (i.e., 118 m^2). The radius of free movement was also larger when relative space per player was set through manipulations of player numbers. A moderate difference was found in the smallest relative space per player (118 m^2), whereas for the 133 and 152 m^2 relative spaces per player the differences were minimal. Concerning the spatial distribution variability, a contrasting trend was found, with larger values of entropy being observed when the relative space per player was set through manipulations of field dimension. In this case, the magnitude of the differences was moderate to large, with the largest differences being found in the 118 and 133 m^2 relative space per player, and a moderate difference in the 152 m^2 relative space per player.

Figure 21 also shows differences within relative spaces per player treatments for the same variables. Manipulations of the relative spaces per player through player numbers had a minimal impact on the effective relative space per player. Differences between relative spaces per player were trivial (118 – 133 m^2 and 133 – 152 m^2) and small (118 – 152 m^2). On the other hand, when field dimensions was manipulated, the effective relative space per player varied more greatly, with moderate differences being found between the smallest relative space per player (118 m^2) and remaining relative spaces per player (133 and 152 m^2). Larger relative spaces per players elicited larger values of this quantity, except in the 133 – 152 m^2 comparison, where larger mean values were found on the 133 m^2 relative space per player, although with a small difference. The same trend was found for the players' radius of free movement, both for manipulations of player numbers and field dimensions, but with lower magnitude differences in the 118 – 152 and 118 – 133 m^2 pairwise comparisons.

With regards to values of participants' spatial distribution variability, Figure 21 (lower right panel) shows that manipulations of player numbers and field dimensions impacted differently on the players' movements on field. Lower relative spaces per player values, set through manipulations of player numbers, showed a tendency for lower values of entropy (small to moderate differences; Figure 22). However, tendencies for larger values of entropy were found for lower relative spaces per player when manipulations of field dimensions were undertaken (with a large difference found between 118 – 152 m^2). Figure 23 displays an example illustrated through exemplar heat maps of one player across all SSCGs conditions.

Concerning the numerical relations established across SSCGs, most of the time players tended to perform with one fewer teammate than opponents inside their relative spaces per player in all treatments. In most cases, the amount of time played without any other players inside the individual relative space per player was the second most prevalent numerical relation (Figure 24). Differences between treatments were found for the 118 and 152 m^2 relative spaces per player, but not for the 133 m^2 relative space per player where differences were all trivial. In the 118 m^2 relative space per player it is worth noting the moderate difference found for NR(=), with manipulations of field dimensions promoting more time spent playing with equal numbers of teammates and opponents inside the individual relative space per player.

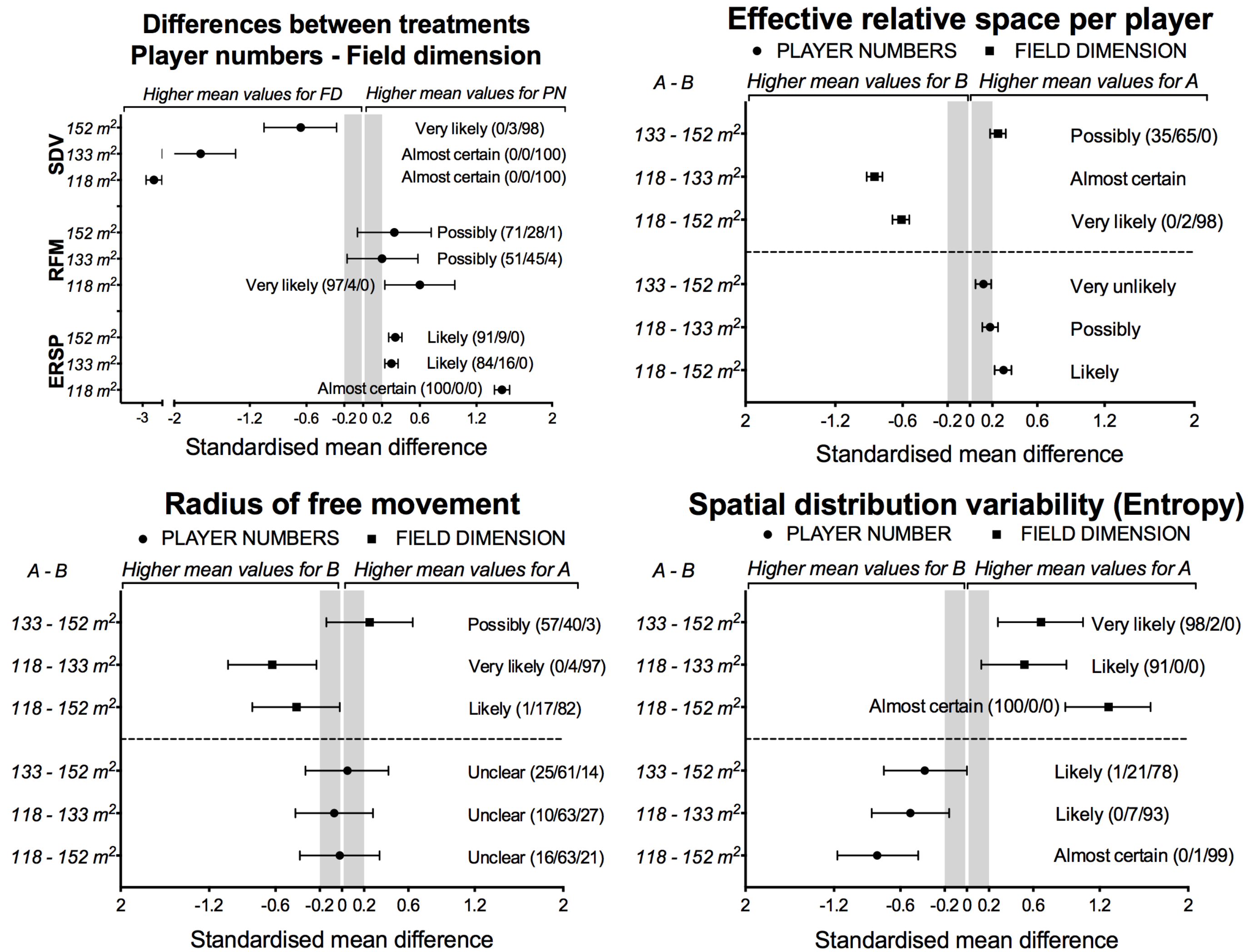

Figure 21 – Standardised mean differences between and within treatments (player numbers – PN – and field dimension - FD) plus quantitative chances of higher or lower differences for (i) effective relative space per player, (ii) radius of free movement and (iii) spatial distribution variability. Error bars represent 90% confidence intervals and probabilities are reported as percentages of greater/similar/lower values. Shaded areas represent trivial differences.

Table 9 – Mean ± standard deviations of the effective relative space per player, radius of free movement and spatial distribution variability according to the relative space per player and constraints-type manipulation.

Relative space per player	Manipulations on player numbers			Manipulations on field dimension		
	Effective relative space per player (m^2)	Radius of free movement (m)	Spatial distribution variability (Entropy)	Effective relative space per player (m^2)	Radius of free movement (m)	Spatial distribution variability (Entropy)
118 m^2	33.86±6.61 n=1083	5.92±1.77 n=54	0.67±0.02 n=54	23.88±6.97 n=1083	5.02±0.98 n=36	0.72±0.01 n=36
133 m^2	32.6±7.1 n=1083	6.05±1.89 n=48	0.68±0.02 n=48	30.39±8.28 n=1083	5.72±1.21 n=36	0.71±0.02 n=0.36
152 m^2	31.71±7.86 n=1083	5.96±1.94 n=42	0.69±0.02 n=42	28.84±9.08 n=1083	5.44±1.03 n=36	0.7±0.02 n=36

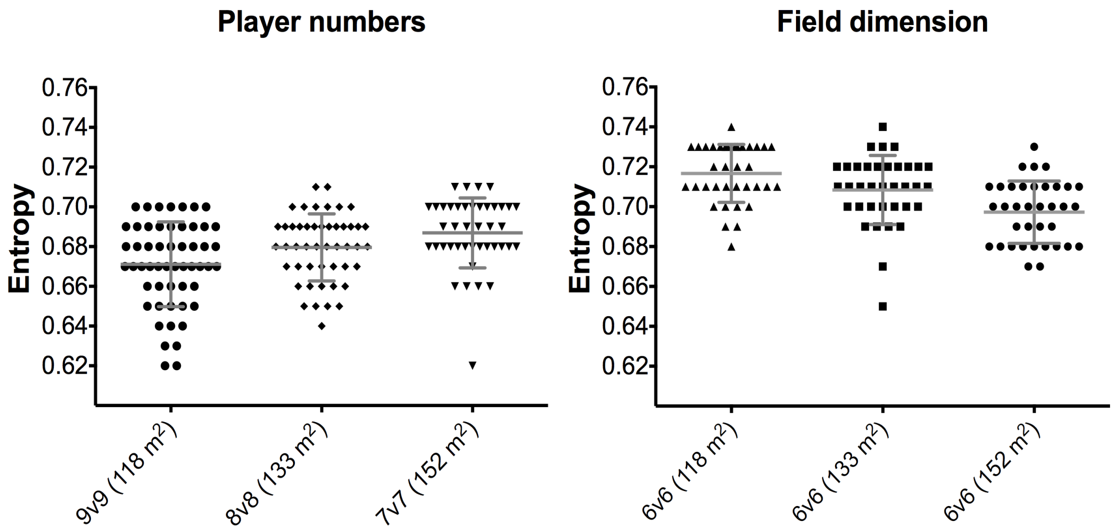

Figure 22 – Mean and distribution of entropy measures. Error bars represent standard deviation.

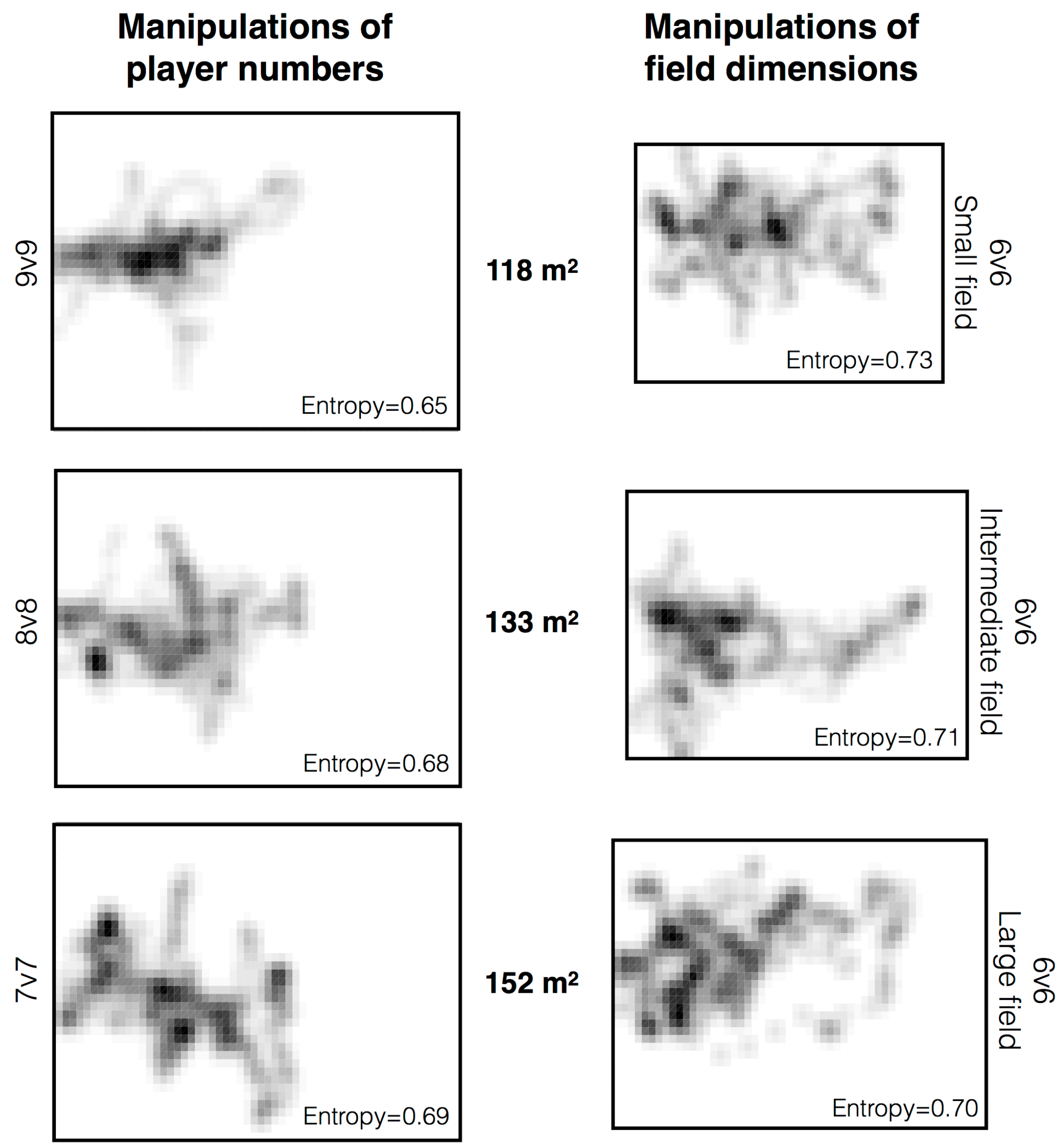

Figure 23 – Exemplar spatial distribution maps and entropy measures of one single player across SSCG.

A moderate difference was also observed for the NR(free), with a superior amount of time played when relative spaces per player were manipulated through player numbers. In the 152 m^2 relative space per player all numerical relations revealed moderate to small differences with the exception of the NR(-2), where differences between player numbers and field dimensions were trivial. Time spent playing in NR(+1) and NR(=) was slightly higher for manipulations of FD, whereas the time spent playing with NR(-1) and NR(free) was slightly larger for manipulations of player numbers.

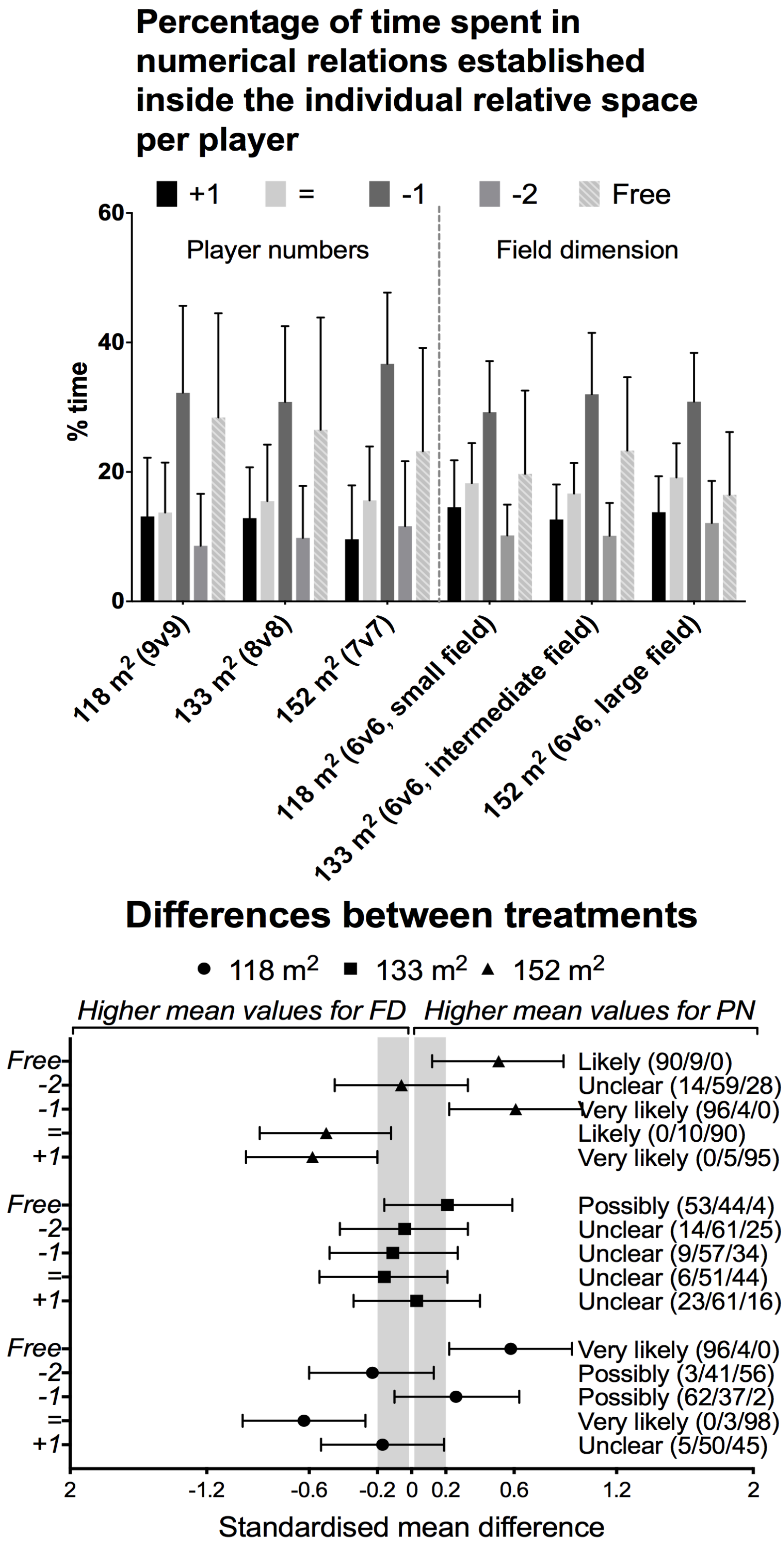

Figure 24 – Upper panel - percentage of time spent in various numerical relations established inside the individual relative space per player (118, 133 and 152 m^2). Error bars depict standard deviation. Lower panel – standardised mean differences between treatments (player numbers – PN – and field dimension – FD) plus quantitative chances of higher or lower differences. Error bars represent 90% confidence intervals and probabilities are reported as percentages of greater/similar/lower values. The shaded area represents trivial differences.

7.4 Discussion

In this study we analysed the influence of manipulations of field dimensions and player numbers on the spatial-temporal characteristics of inter-individual coordination tendencies of under-15 yr old youth football players emerging within the same replicated dimensions of relative space per player during SSCG. The dependent variables encompassed the effective relative space per player, radius of free movement, variability of the players' spatial distributions and the numerical relations established in the vicinity of each player.

Results showed that, even though manipulations of player numbers and field dimensions may be used to set the same relative spaces per player, emergent interpersonal coordination tendencies of players during each constraining SSCGs differed. This finding suggests that players co-adapted to the specific constraints being manipulated in the experimental treatments. This finding fits with the tendency in complex biological systems to self-organise as they encompass a number of components (e.g. players) with the capacity to interact and form emergent patterns of collective behaviours (Davids, Araújo, et al., 2005; Kelso, 1995; Kugler et al., 1980). In general, during manipulations of player numbers, higher values of the effective relative space per player, radius of free movement and lower spatial distribution variability emerged in all pre-set relative spaces per players. This suggests that each player afforded more space to play and was required to perform in more regular zones of the field than when performing in equivalent areas set through manipulations of field dimensions.

Manipulations of player numbers did not promote meaningful changes in the values of the effective relative space per player and in their radius of free movement. However, the first seemed to be greater when a larger number of players were involved (Table 9). In contrast, when increases of field dimensions were undertaken, the effective relative space per player increased along with concurrent increases in values of distance to nearest opponents. Accordingly, adding extra players to teams performing on a field of constant dimensions seemed to provoke a reorganization of the players. This led them to display a wider dispersion on field to achieve similar interacting patterns of behaviour (i.e., leading to similar amounts of space per player and similar distances to opponents). As performance area dimensions increased, greater effective relative spaces per player were available to be explored with concurrent increases in their radius of free movement.

Similar co-adapting behaviours have been observed in other studies, in terms of inter-team distance values, as a result of field dimensions manipulations (Frencken et al., 2013; Silva, Duarte, et al., 2014). This modification may have created more possibilities for each player to pass the ball and maintain possession since opponents were further away from ball passing trajectories (Travassos et al., 2012; Vilar et al., 2012). Conversely, on smaller performance areas fewer opportunities may have been provided to maintain ball possession due to decreasing distances of opponents to ball trajectories (Vilar et al., 2014). This assumption is corroborated in studies that have analysed the technical determinants of SSCGs. Kelly & Drust (2009) and Dellal et al. (2012) observed a greater frequency of tackles, challenges, loss of ball possessions and physical contacts in SSCGs played on smaller performance areas.

Another important aspect from this study to retain is that the effective relative spaces per player found for all treatments were much smaller than those theoretically set by the simple quotient of the total field area per number of players (Tables 1 and 2). These findings do not corroborate the recommendations of Fradua et al. (2013) for determining the appropriate size of SSCG fields, possibly because they considered the total SSCGs field area rather than an effective playing space area inside the SSCGs fields. Further studies are needed to clarify this issue considering the effective playing area rather than the total SSCGs area and using a broader participants sample (of varied ages and skills).

Concerning the numerical relations established inside each relative space per player treatment, a numerical disadvantage of one player was dominant over time, intersected by periods of time without any teammates or opponents in the vicinity of each player. Larger periods of time under numerical advantage were observed for field dimensions having 118 and 152 m^2 relative spaces per player, but not 133 m^2, where manipulations of field dimensions or player numbers promoted similar values of numerical relations.

Larger periods of numerical disadvantage were observed during manipulations of player numbers and the 118 and 152 m^2 relative spaces per player treatments, but not on the 133 m^2 treatment. Additionally, in the 152 m^2 condition, larger periods of time were played under a numerical superiority of one player. The creation of numerical dominance is key for increasing offensive success and defensive stability in competitive team games (Silva, Travassos, et al., 2014; Vilar et al., 2013).

The lack of a solid theoretical rationale to explain the aforementioned results raises the need for further work clarifying the relationship between player numerical relations and different SSCGs formats. A major task here is to scrutinize performance interactions during transitions between attacking and defending phases. Independently, constraints on field dimensions and player numbers clearly provided distinct values of numerical relations in the 118 and 152 m^2 relative space per players. Manipulations of field dimensions elicited a greater number of situations with a numerical advantage whereas player numbers modifications promoted more situations where players stood alone without any other individuals in their action zones, or with a numerical disadvantage of one player.

The spatial distribution of players on field was more irregular for manipulations of field dimensions with larger differences observed for constraints manipulations in the smaller relative spaces per player (118 m^2). Players also displayed more irregular spatial distributions when fewer numbers of individuals performed on fixed field dimensions and when a fixed number of players were involved on fields of smaller dimensions. This finding provides information about the specificity of tactical roles required for each SSCG manipulation. More irregular spatial distributions seem to appeal to more broad tactical roles, while restricted spatial distributions suggested a more structured style of play, according to specific positioning and playing roles. Similar findings where observed by Silva, Aguiar, et al. (2014) for national- and regional-level players performing in SSCG with different field dimensions. The authors verified that both national- and regional-level players covered highly irregular pitch areas when field dimensions were smaller.

The current study has some limitations that should be acknowledged. Larger samples of participants of varied ages and skill levels should be considered in future studies as well as the manipulation of other relative space per player areas, player numbers (e.g., 3v3, 4v4, 5v5) and field dimensions. The type and number of technical actions performed may also be considered in order to verify whether game behaviours, like shooting or tackling, for instance, occur more often in specific SSCG contexts.

7.5 Conclusions

This study showed how, at an inter-individual level of analysis, football players' spatial distributions on field can be influenced differently when player numbers or field dimensions manipulations are undertaken. The findings of this study provided a theoretical rationale for explaining why space and player numbers should be manipulated in training tasks, providing relevant implications for enhancing tactical behavioural interactions of developing players. The manipulation of such constraints leads to the specification of different informational sources that invite players to perform functional patterns of behaviour without coaches explicitly prescribing *a priori* solutions for them (Davids, Jia Yi, et al., 2005). Such coordination tendencies can be harnessed by practitioners to lead performers towards stable performance behaviours. Such behaviours should be verified in further studies through the analysis of inter-individual, intra- (e.g., stretch indices, team length, team width, team shape, etc.) and inter-team (e.g., effective playing area, distance between lines-forces, etc.) variables as well as technical actions. One possibility to extend knowledge about performance in SSCGs is by cross-checking information on technical actions (e.g., passes, shots, tackles, etc.) with the dynamic behaviours of players and teams (e.g., the direction and type of pass when more space is available to play or when favourable or unfavourable numerical relations emerge during the game).

7.6 Practical applications

In the context of this study, favouring attacking plays or augmenting defensive pressure could be obtained by decreasing and increasing the effective relative space per player and the players' range of free movement (without opponents), accordingly. Promoting favourable or unfavourable numerical relations near the vicinity of each player can also impact on the effectiveness of attacking and defending actions. Manipulating player numbers or field dimensions could also be used to shape the depth of players' tactical roles. Playing with fewer players on fields with fixed dimensions or with a fixed number of players on smaller performance areas seem to elicit broader spatial distributions and vice-versa.

7.7 Acknowledgements

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7.8 References

Batterham, A., & Hopkins, W. (2005). Making meaningful inferences about magnitudes. *Sportscience, 9*, 6-13.

Buchheit, M., & Mendez-Villanueva, A. (2014). Effects of age, maturity and body dimensions on match running performance in highly trained under-15 soccer players. *Journal of Sports Sciences, 32*(13), 1271-1278.

Casamichana, D., & Castellano, J. (2010). Time-motion, heart rate, perceptual and motor behaviour demands in small-sides soccer games: effects of pitch size. *Journal of Sports Sciences, 28*(14), 1615-1623.

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2006). Nonlinear pedagogy: A constraints-led framework for understanding emergence of game play and movement skills. *Nonlinear Dynamics, Psychology, and Life Sciences, 10*(1), 71-103.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Coutts, A. J., & Duffield, R. (2010). Validity and reliability of GPS devices for measuring movement demands of team sports. *Journal of Science & Medicine in Sport, 13*(1), 133-135.

Davids, K., Araújo, D., Correia, V., & Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exercise and Sport Sciences Reviews, 41*(3), 154-161.

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of dynamical system theory to Football. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science & Football V* (pp. 556-569). Oxon: Routledge.

Davids, K., Chow, J. Y., & Shuttleworth, R. (2005). A Constraints-based Framework for Nonlinear Pedagogy in Physical Education. *Journal of Physical Education New Zealand, 38*, 17-29.

Dellal, A., Owen, A., Wong, D. P., Krustrup, P., van Exsel, M., & Mallo, J. (2012). Technical and physical demands of small vs. large sided games in relation to playing position in elite soccer. *Human Movement Science, 31*(4), 957-969.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sport teams as superorganisms: implications of biological models for research and practice in team sports performance analysis. *Sports Medicine, 42*(8), 633-642.

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., & Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *Journal of Systems Science and Complexity, 26*, 62-72.

Fradua, L., Zubillaga, A., Caro, Ó., Iván Fernández-García, Á., Ruiz-Ruiz, C., & Tenga, A. (2013). Designing small-sided games for training tactical aspects in soccer: Extrapolating pitch sizes from full-size professional matches. *Journal of Sports Sciences, 31*(6), 573-581.

Frencken, W., van der Plaats, J., Visscher, C., & Lemmink, K. (2013). Size matters: Pitch dimensions constrain interactive team behaviour in soccer. *Journal of Systems Science and Complexity, 26*(1), 85-93.

Hill-Haas, S., Dawson, B., Impellizzeri, F. M., & Coutts, A. J. (2011). Physiology of small-sided games training in Football. A systematic review. *Sports Medicine, 41*(3), 199-220.

Hopkins, W. (2002). Probabilities of clinical or practical significance [Versão eletrónica]. *Sportscience, 6*, disponível em sportsci.org/jour/0201/Statistical_vs_clinical.ppt.

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise, 41*, 3-13.

Johnston, R., Watsford, M., Pine, M., Spurrs, R., & Sporri, D. (2013). Assessment of 5 Hz and 10 Hz GPS units for measuring athlete movement demands. *International Journal of Performance Analysis in Sport, 13*, 262-274.

Kelly, D., & Drust, B. (2009). The effect of pitch dimensions on heart rate responses and technical demands of small-sided soccer games in elite players. *Journal of Science and Medicine in Sport, 12*(4), 475-479.

Kelso, J. A. S. (1995). *Dynamic patterns: the self-organizing of brain and behavior*. Massachusetts: MIT Press.

Kugler, P. N., Kelso, J. A. S., & Turvey, M. T. (1980). On the concept of coordinative structures as dissipative structures: I. Theoretical lines of convergence. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in Motor Behavior* (pp. 3-47). Amsterdam: North-Holland Publishing Company.

Passos, P., Araújo, D., Davids, K., & Shuttleworth, R. (2008). Manipulating constraints to train decision making in Rugby Union. *International Journal of Sports Science & Coaching, 3*(1), 125-140.

Platt, D., Maxwell, A., Horn, R., Williams, M., & Reilly, T. (2001). Physiological and technical anlysis of 3v3 and 5v5 youth football matches. *Insight, 4*(4).

Shannon, C. (1948). A mathematical theory of communication. *The Bell System Technical Journal, 27*(3), 379-423.

Silva, P., Aguiar, P., Duarte, R., Davids, K., Araújo, D., & Garganta, J. (2014). Effects of pitch size and skill level on tactical behaviours of Association Football players during small-sided and conditioned games. *International Journal of Sports Science & Coaching, 9*(5), 993-1006.

Silva, P., Duarte, R., Sampaio, J., Aguiar, P., Davids, K., Araújo, D., & Garganta, J. (2014). Field dimension and skill level constrain team tactical behaviours in small-sided and conditioned games in football. *Journal of Sports Sciences*, 1-9.

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*, 765-772.

Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D., & Garganta, J. (2014). Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams. *PloS One, 9*(9), e107112.

Sinnott, R. W. (1984). Virtues of the Haversine. *Sky and Telescope, 68*(2), 159.

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., & Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychology of Sport & Exercise, 13*(2), 216-223.

Travassos, B., Vilar, L., Araújo, D., & McGarry, T. (2014). Tactical performance changes with equal vs unequal numbers of players in small-sided football games. *International Journal of Performance Analysis in Sport, 14*(2), 594-605.

Vilar, L., Araújo, D., Davids, K., & Bar-Yam, Y. (2013). Science of winning soccer: emergent pattern-forming dynamics in Association Football. *Journal of Systems Science and Complexity, 26*(1), 73-84.

Vilar, L., Araújo, D., Davids, K., Correia, V., & Esteves, P. (2013). Spatial-temporal constraints on decision-making during shooting performance in the team sport of futsal. *Journal of Sports Sciences, 31*(8), 840-846.

Vilar, L., Duarte, R., Silva, P., Chow, J. Y., & Davids, K. (2014). The influence of pitch dimensions on performance during small-sided and conditioned soccer games. *Journal of Sports Sciences*, 1-9.

Withagen, R., Poel, H. J. d., Araújo, D., & Pepping, G.-J. (2012). Affordances can invite behaviour: Reconsidering the relationship between affordances and agency. *New Ideas in Psychology, 30*, 250-258.

Chapter 8

Final Considerations

The main aims of this thesis were (i) to propose an explanation of team coordination in football (here considered to depict tactical behaviour) (ii) to analyse effects of practice on emergent team coordination and (iii) to evaluate a constraints-based approach as a pedagogical tool to shape tactical behaviours. To fulfil this purpose, a position statement article was elaborated and five empirical studies were conducted, framed by an ecological dynamics theoretical rationale. It was highlighted that coordination in team sports can be achieved through the perception of shared affordances that support the formation of interpersonal synergies. The programme of work also demonstrated how practice impacts on the perceptual attunement to shared affordances and synergy formation and that manipulations of specific key task constraints during SSCGs can be used to shape distinct interpersonal coordination patterns (or tactical behaviours). In this chapter the main findings of the experiments are highlighted along with an outline of conclusions and theoretical and practical implications.

8.1 Synthesis of main findings

In chapter II, an explanation for team coordination in sports was proposed and contrasted with traditional models of team cognition. The latter are grounded on the premise that there is an internalization of shared knowledge about the performance environment amongst all team members, through the form of mental representations or schemas responsible for the organization and regulation of team behaviours. It has been traditionally argued that team members can maintain some common representations or understanding that would allow them to achieve a state of group coordination. Forming clear expectations about each other's actions and selecting appropriate goal-directed solutions to put into practice would achieve group coordination.

The inability of this theoretical approach to clarify some issues like individual schema reformulations when changes occur in the schemas of other teammates or even the sustenance of a shared mental representation by players perceiving different informational cues (following their positions on field) led to a proposal of more congruous explanations of team coordination. An ecological dynamics perspective emphasises the role of perception and action in the regulation of movement by advocating that individuals gain knowledge of the performance environment through direct perception of their possibilities for action (*affordances*) related to what they can do with and in the environment. Furthermore, humans are also very accurate at perceiving another person's action capabilities and intentions, which enables them to adjust their behaviours to functionally adapt to those of other teammates and opponents and act coherently with respect to specific task goals in a performance context. In this sense, team coordination depends on being collectively attuned to affordances *of* others and affordances *for* others during competitive performance (Passos et al., 2012). We hypothesised that this process could be enhanced through practice, contributing to the reduction of the immense degrees of freedom of all players in a team through the formation of synergies, or coordinative structures, grounded on the perception of shared affordances. Such synergies correspond to the numerous linkages between the players as degrees of freedom in a collective system required for the reduction of system dimensionality needed for system re-organization into structures that are specific to the task at hand (for instance, transitioning up the pitch together by moving synchronously towards the opposition goal during a fast break attack). Thus, it was proposed that the coupling of the players' degrees of freedom into interpersonal synergies is based upon a social perception-action system supported on the perception of shared affordances that continuously emerge through the reciprocity and interdependency of their actions.

In chapter III evidence for this assumption was provided by analysing the effects of thirteen weeks of practice on synergy formation of two teams of recreational players during performance. Team synchronization resulting from the rhythmic ebb-and-flow movements during performance was shown to emerge from a continuous process of synergy formation that rapidly oscillated between peaks of player couplings, suggesting that moving players provide informational properties that invite actions from other members of the complex adaptive system (players) over different timescales. As some players advanced up-field, remaining teammates were compelled to follow their movements in corresponding to team patterns of play. Practice was shown to improve team synchronization speed, captured as reduced time-delays in the players' co-positioning readjustments, resulting in faster re-establishment of synergies. This process emerged after just two hours of practice per week in two newly formed football teams.

We have also emphasised, in chapter II, the role of constraints on shaping shared affordances available for perceptual systems and the importance of this perspective for experimental and training design in the field of team sports. Manipulating specific key task constraints may channel inter-individual, intra- and inter-team tactical behaviours into stable and functional coordination patterns during practice by promoting changes in the players' spatial-temporal interactions. Small-sided and conditioned games (SSCGs) were proposed as feasible practice tasks for the acquisition of shared affordances. Therefore, in chapters IV to VII such practice tasks were used as experimental tasks to demonstrate that manipulations of specific task constraints shape distinct types of tactical behaviours that emerge from the interaction between co-operating players and competing teams within the performance environment without the need of *a priori* prescribed instructions.

Specifically, in chapter IV the variability of the players' movement trajectories during performance in SSCGs was analysed by varying performance area dimensions. Variability analyses of players' spatial distributions provided information about the width of each player's tactical role. On the other hand, variability in the distance to their trajectories' geometrical centre (i.e., the loci) over time provided information about the time-evolving nature of their movements on field. Results confirmed distinct inter-individual coordination patterns according to field dimensions. As playing areas increased, the players' spatial distribution (i.e., their action zones) tended to become more restricted. Players also showed a near cyclical sinusoidal movement pattern across match play reflecting a tendency to travel around a preferred reference zone during the rhythmic ebb-and-flow of attacking and defending. The periodicity of these movements increased in larger fields, despite the distance to their positional locus has increased.

The players' skill level was also observed as an important constraint on emergent behaviours. More skilled players were revealed to be more sensitive to pitch size manipulations by displaying more prominent differences in behaviours from interventions to interventions. They also showed higher levels of variability in the small and intermediate pitches, here interpreted as functional variability necessary to cope with the reduced time and space available to play on smaller pitches.

In chapter V, analysis of effects of field dimension on tactical behaviours were extended to the intra- and inter-team level. Effective playing space was shown to augment effects of field dimension, with team players covering more ground when playing on larger fields. The shape of this effective playing space varied according to the players' skill level. More skilled teams showed elongated match shapes on larger fields whereas less skilled teams maintained similar length and width characteristics on all field dimensions. This finding suggests that players can adopt different playing styles, according to field size and skill level. It is likely that possibilities for action (e.g., dribbling, running with the ball, shooting, type of pass, etc.) may change according to the effective playing area and match shape variations due to altered spatial-temporal relations between players, although more research is needed to confirm this idea.

The available space between both teams (with respect to the players' nearest opponents) also increased with field dimension, without any differences between skill levels, though, implying more available space and time for players to make decisions. Nonetheless, the more skilled group presented higher and unpredictable values of distances to their nearest opponents, interpreted as their superior ability to create space and avoid close marking.

The findings of these studies (chapters IV and V) revealed the behavioural specificity induced by distinctive field dimensions in SSCGs and skill level.

In chapter VI, a social neurobiological systems perspective was followed to analyse effects of manipulations in numerical relations on players' co-adapting behaviour to ecological constraints of performance during SSCGs in teams with differentiated skill level. At the inter-individual scale of analysis, skill level played an important role in determining the division of labour among team members, the areas of their dominant regions and the predominant direction of their movements on field. The dominant regions were larger and smaller for the overloaded and underloaded teams of more skilled players, respectively, when a difference of two players was applied. The less skilled players presented larger dominant regions when a difference of one player was established. Skilled players were also more tactically balanced as they occupied the field more rationally and displayed more similar movement amplitudes in the longitudinal and lateral directions than their less skilled counterparts. In this sense, skill level constrained the perception of different action possibilities (shared affordances) and the division of labour.

Overloaded teams also tended to advance up-field when opponents lost players but without meaningful changes in their dispersion values, whereas underloaded teams tended to retreat nearer their own goal and contract in order to protect it. This occurred in both groups, independent of skill level. However, more skilled players were more capable of pressing the underloaded team's defensive line in order to disturb their defensive stability by shortening the distance between attacking and defending lines. These findings evidenced that numerical relations clearly constrained inter-individual, intra- and inter-team coordination tendencies through exploratory performance behaviours during pursuit and creation of shared affordances.

Data from chapter VII showed that the establishment of the same relative space per player in SSCGs through manipulations of player numbers or field dimensions might impact differently on the players' interpersonal interactions during performance. Each type of constraint specified different informational sources that invited players to perform distinct inter-individual coordination patterns. Specifically, manipulations in player numbers elicited larger playing areas allocated to each player and larger distances to nearest opponents per player than did manipulations on field dimensions. However, it was observed that different relative playing areas per player set by field dimensions promoted distinctive interpersonal coordination patterns. In contrast, mere variations in player numbers did not promote meaningful changes in coordination tendencies, when referring to the aforementioned quantities. The numerical relations established near the vicinity of each player were also different for both types of constraints manipulation. In this sense, favourable or unfavourable contexts for attacking and defending can be recreated by simply manipulating such types of constraints. Furthermore, playing with fewer players in an area with fixed dimensions (i.e., on a larger relative space per player) or with a fixed number of players on smaller pitches (i.e., on a smaller relative space per player) seemed to elicit broader spatial distributions of players on field, and vice-versa.

8.2 Theoretical implications

As previously mentioned, an ecological dynamics perspective advocates that the performance environment surrounding individuals displays informational energy fields for perceptual systems that specify affordances or possibilities for action (Gibson, 1966, 1979). As proposed in chapter II, in the context of team coordination, affordances are collective (Reed, 1996) in the sense that they can be perceived by a group of individuals trained to become perceptually attuned to them. Thus, affordances are sustained by common goals shared between players acting altruistically to achieve functional group coordination, acquired through practice. In chapter III it was highlighted how players in a team can display synchronised movements on-field by sharing common objectives during attacking and defending (i.e., moving up-field to approach the opposition goal when attacking and when moving backwards to protect the goal when defending). Team synchrony was sustained by increasingly faster establishment of synergies over time, as a consequence of practice. Informational constraints emanating from the movements of players regulated functional patterns of coordination between individuals on the basis of coupling tendencies. This emerged because players learned to become collectively attuned to shared affordances (of self and affordances of others) with each individual reciprocally influencing and being influenced by behaviours of teammates. This is also a central feature of a synergy – the ability of one component to react to changes in others (Riley et al., 2011) – that highlights the interdependence of players' decisions and actions.

Affordances specify more than simple action possibilities, being referred to as interaction or relational properties (Turvey, 1992). In this sense they capture the fit between performer constraints and properties of the environment (Fajen & Turvey, 2003), including the informational properties provided by the movements of teammates, opponents and the ball. Furthermore, by interacting with constraints, players are not merely acting upon specifying information from the environment. They are also actively engaged in creating action opportunities for themselves and for teammates by changing informational fields. In chapter III, for instance, the observed oscillating property of synergy formation supports the idea that moving players provide informational properties that offer or invite actions for teammates, changing over different timescales. As some players moved forward or backward in the field, other players were compelled to follow in corresponding to team patterns of play. The reciprocal information-movement relations of players constantly actualised the state of relation between each individual and the performance context allowing the emergence of coordinated (functional) team movements (Fajen & Turvey, 2003).

In chapters IV to VII, manipulation of specific key task constraints was observed to channel individual and team tactical behaviours into stable and functional coordination patterns (or attractors) during goal directed team activities (Araújo, Davids, Bennett, Button, & Chapman, 2004; Handford, Davids, Bennett, & Button, 1997) without the necessary need of prescriptive instructions. In all experiments players were shown to mutually interact with their teammates and opponents at different levels of social organization in pursuit of functional patterns of interpersonal coordination without being previously educated about how they should perform. Players evidenced self-organizing properties sustained by the specific informational resources resulting from the spatial-temporal relations emerging within each SSCG. Therefore, manipulations in task constraints such as field dimensions, player numbers, numerical relations, etc., shape distinct informational resources that specify shared affordances for specific group tactics to emerge during practice.

Slight changes in task constraints can influence the adaptive coordinative structures that emerge as individuals seek, discover and explore functional coordination solutions (Davids et al., 2007). More skilled players are able to perceive affordances in many subtle ways. The observed effects of skill level on co-adaptation to task constraints in chapters IV, V and VI support the idea that players calibrate information about action capabilities of themselves and others, allowing them to pick the affordances that they can satisfy and discard those that are not within their action capabilities (Fajen et al., 2008). For instance, when manipulations in field dimensions were applied (chapters IV and V), more skilled players evidenced increased movement variability on small pitches and higher unpredictable distance values to nearest opponents, showing different negotiation of constraints influenced by skill level.

8.3 Concluding remarks

Based on the findings of the studies that composed this dissertation, the following conclusions can be outlined:

- Team tactical behaviours are sustained (and must be understood) at the level of the player-player-environment system. Their mutuality and reciprocity forms the context in which movement (of players and the ball) provides performers with affordances (for self and for others) that persist, emerge and dissolve over different time-scales, as a function of team and individual goals;

- Shared-affordances-based coordination harnesses the capacity of teams to re-organize their coordinative structures, or synergies, allowing players to act as a cohesive unit at the level of interpersonal interactions by reduction of the system's degrees of freedom;

- Practice can improve team synchronization speed translated in faster reestablishment of synergies;

- Tactical behaviours are malleable and can be shaped during practice in SSCGs by simply manipulating key task constraints to promote the emergence of affordances as different tactical adaptations;

• Players' individual characteristics, like skill level, impact on the perception and creation of shared affordances, and consequently, on the tactical coordination tendencies emerging at different levels of social coordination.

8.4 Practical applications

Overall, the findings of this thesis support the adoption of a *hands-off* coaching and teaching style (i.e., a learner-centred approach) for shaping team tactical behaviours, which signal a different role for the coach/practitioner than that usually assumed in traditional coaching models (i.e., the coach viewed as responsible for leading the learning process). We propose a non-linear pedagogy approach (Chow et al., 2006) to shape tactical behaviours that recognize team tactical solutions as products of self-organization facilitated through exploitation of constraints and shared affordances. Practice should, then, encourage emergence of functionally relevant coordination solutions by manipulations of the player-player-environment interactions. This can be undertaken by altering relevant task, environmental and performer constraints (Chow et al., 2007; Renshaw et al., 2010) to replicate the specific dynamics existing in a performance context (Davids et al., 2008). As argued in chapters I and II, instructional constraints can be used *prior to* performance in order to educate the perception of specific possibilities for action and constrain action initiation (Araújo et al., 2009). Usual off-field manipulation strategies include verbalization and dialogues with the players, multimedia presentations (videos, images), imagery, etc. (Passos, 2010). But during performance, a shared-affordances-based coordination will likely be more influential on emergent team behaviour.

Importantly, in this thesis it is advocated that shaping tactical behaviours involves shaping the formation of synergetic relations established between players in a complex social entity (i.e., a sports team). In this sense, natural coordination tendencies emerging between individual players with specific skills and mindsets characterize a 'superorganismic' entity (Duarte et al., 2012) the same way in which genes, personality or physical capabilities interact to define each individual player's intrinsic dynamics. This idea implies that each team possesses its own idiosyncratic properties that are shaped by many constraints, such as the club's history, playing philosophy, the players' learning and playing experiences, etc. This constitutes what Rietveld and Kiverstein (2014) called 'the form of life' in a performance environment and justifies the need to formulate a new class of constraints referring to the team's intrinsic dynamics. This is especially important for coaches because tactical behaviours can shape the emergence of different collective coordination patterns (i.e., playing styles) that may or may not suit a team's intrinsic dynamics, just like an idealized biomechanical movement pattern may or may not satisfy an individuals' organismic constraints.

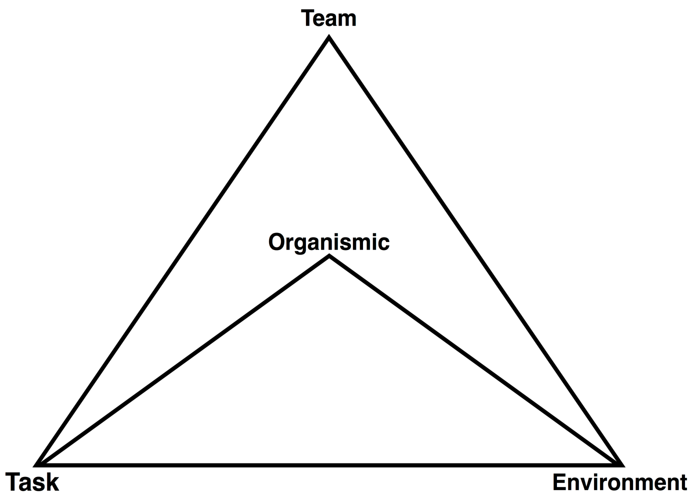

Figure 25 – Representation of the four classes of constraints that interact to shape tactical behaviours.

Tactical behaviours may then be shaped through manipulations of four (and not just three) interacting classes of constraints – task, environment, organismic and *team* constraints (Figure 25). Examples of manipulation of team constraints may include (i) off-field manipulations (see Passos, 2010), (ii) selection of players with different characteristics (i.e., different organismic constraints), (iii) altering the team's dispositional structure (e.g., from 1-4-3-3 to 1-4-4-2), or (iv) through substitution of players during competitive fixtures. On-field manipulations of team constraints can be performed by educating the players to perceive shared affordances that sustain desired team behaviours (or collective principles of play) through practice.

This programme of work has identified specific tactical behaviours emerging from manipulations of task constraints with interacting organismic (e.g., skill level) and team constraints of the participant teams (although the participant teams intrinsic dynamics have not been the focus of research). For instance, manipulations of field dimensions in SSGCs can be used to shape the width of tactical roles. Smaller fields constrain players to play in more variable zones of the field and, thus, assume more diversified functions in the team (e.g., playing on the left and right corridors; playing as the last player on a defensive line or as a forward). This also requires players to be constantly aware of the positioning of other teammates (i.e., higher tactical awareness) and opponents in order to constantly re-adjust their own positioning to ensure a balanced occupation of the field. On the other hand, larger fields appeal to a more structured playing style, according to specific positions (e.g., playing on the left side of the pitch). Furthermore, SSCGs played in larger fields promote the availableness of more space between attackers and defenders. These findings are particularly useful for coaches of youth football. For instance, larger field SSCGs seem to be more appropriate to introduce the game to novice players, since in these performance contexts they mainly have to focus on covering a restricted territory following attacking and defending phases while having more space and time to make decisions.

Manipulations of numerical relations can be used to facilitate attacking actions of overloaded teams, since with a numerical difference of one and two players there was a tendency to approach the underloaded team's goal. More space was also created at the back of the overloaded team and on the wings, providing good conditions for stimulating build up play. Moreover, the underloaded teams tended to contract, probably because they spent more time engaged in defending actions due to difficulties of maintaining ball possession when playing with fewer players. Thus, an exacerbation of defending skills can be obtained by placing a team under a numerical disadvantage.

According to the findings of chapter VII, the relative space per player in SSCGs should not be considered as a guideline for designing practice tasks since the same areas per player can be obtained by manipulating field dimensions or player numbers, but, in turn, have shown to promote distinct tactical adaptations of players. For instance, the same relative areas of play established by each one of these constraints have shown to promote different individual spatial distributions and numerical relations near the vicinity of each player.

Individual constraints, like the learners' skill level, shall also be accounted when designing practice tasks. Different individual capabilities have resulted in different tactical adaptations to SSCG requirements. Therefore, placing and maintaining the athlete under optimal constraints to facilitate maximum adaptation should therefore be the primary goal of any coach.

Finally, SSCGs can be used as an evaluation tool of emerging talent in football. More skilled players display higher levels of movement variability and are more difficult to mark during performance in SSCGs played in small fields. They are also more tactically balanced in respect to the division and coverage of specific zones of the field.

8.5 Shaping tactical behaviours… future perspectives

In this thesis, the identified tactical behaviours on chapters IV to VII are the result of self-organizing processes under specific task constraints but free from the influence of instructional and feedback constraints by the experimenters or the participants' coaches. In a training setting, coaches should be aware of the tactical behaviours that they wish to stimulate on their teams with any given exercise prior to administering them to the team. Given the reduced number of studies analysing the tactical behaviours emerging under specific task constraints and the behavioural variability caused by individual characteristics (height, skill, fitness level, etc.), sports scientists and practitioners need to work together to fully understand the nature of the *team*, individuals, task, and environmental constraints impacting the coaches' tactical conceptions. The future may therefore hold a new position on coaching staffs by incorporating behavioural specialists capable of capturing, analysing and improving tactical behaviour of players individually and of the team, collectively, during training and competition, towards desired playing patterns and styles of coaches.

In this particular context, technological resources and mathematical modelling will likely play a major role on the monitoring and enhancement of tactical performance. For instance, global positioning systems (or other player tracking systems) should further integrate tactical and nonlinear measures (like those used in this thesis) to cope with the dynamics of tactical behaviour. As in fitness assessments and testing, tactical databases could then be created and used to help model and predict future performances. An example, of this procedure was described on chapter III, where team tactical features, depicted by the formation of synergies, were analysed throughout a period of thirteen weeks and correlated with performance indicators.

Furthermore, new forms of constraints manipulation can be introduced with the help of technology. For instance, digital stopwatches (already used other sports teams like in basketball matches), setting a specific time for players to accomplish a given objective (e.g., shooting at goal) may place relevant constraints on coordination. Other examples may include the development of adjustable boundary lines or markings (for example, through projected light beams) able to follow the teams' movements and set new playing areas and team shapes, according to field zone. The creation of goals that can be re-sized during practice and change the existing possibilities for shooting and scoring available for players constitutes another possibility of future pedagogical resources. They can be used by coaches to change the particular set of constraints available for attacking and defending actions without having to constantly prescribe verbal performance solutions or interrupting practice.

8.6 References

Araújo, D., Davids, K., Cordovil, R., Ribeiro, J., & Fernandes, O. (2009). How does knowledge constrain sport performance? An ecological perspective. In D. Araújo, H. Ripoll & M. Raab (Eds.), *Perspectives on cognition and action in sport* (pp. 119-131). New York: Nova Science Publishers, Inc.

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2006). Nonlinear pedagogy: A constraints-led framework for understanding emergence of game play and movement skills. *Nonlinear Dynamics, Psychology, and Life Sciences, 10*(1), 71-103.

Chow, J. Y., Davids, K., button, C., Shuttleworth, R., Renshaw, I., & Araújo, D. (2007). The role of nonlinear pedagogy in physical education. *Review of Educational Research, 77*(3), 251-278.

Davids, K., Araújo, D., Button, C., & Renshaw, I. (2007). Degenerate brains, indeterminate behavior, and representative tasks: implications for experimental design in sport psychology research. In G. Tenenbaum & R. C. Eklund (Eds.), *Handbook of Sport Psychology* (3rd ed., pp. 224-244). New Jersey: John Wiley & Sons, Inc.

Davids, K., Button, C., & Bennett, S. (2008). *Dynamics of skill acquisition: a constraints-led approach.* Champaign (IL): Human kinetics.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sport teams as superorganisms: implications of biological models for research and practice in team sports performance analysis. *Sports Medicine, 42*(8), 633-642.

Fajen, B., Riley, M., & Turvey, M. (2008). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*(1), 79-107.

Fajen, B., & Turvey, M. (2003). Perception, categories, and possibilities for action. *Adaptive Behavior, 11*, 276-278.

Gibson, J. (1966). *The senses considered as perceptual systems*. Boston: MA: Houghton Mifflin.

Gibson, J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Passos, P. (2010). *Rugby*. Cruz Quebrada: FMH Edições.

Passos, P., Cordovil, R., Fernandes, O., & Barreiros, J. (2012). Perceiving affordances in rugby union. *Journal of Sports Sciences, 30*(11), 1175-1182.

Reed, E. S. (1996). *Encountering the world: Toward an ecological psychology*. Oxford: Oxford University Press.

Renshaw, I., Chow, J., Davids, K., & Hammond, J. (2010). A constraints-led perspective to understanding skill acquisition and game play: a basis for integration of motor learning theory and physical education praxis? *Physical Education and Sport Pedagogy, 15*(2), 117-137.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Rietveld, E., & Kiverstein, J. (2014). A Rich Landscape of Affordances. *Ecological Psychology, 26*(4), 325-352.

Turvey, M. (1992). Affordances and prospective control: an outline to the ontology. *Ecological Psychology, 4*(3), 173-187.