RODRIGO DE MIRANDA MONTEIRO SANTOS

PADRÕES DE COORDENAÇÃO INTERPESSOAL NO FUTEBOL: ANÁLISE DAS RELAÇÕES NUMÉRICAS RELATIVAS EM SEQUÊNCIAS OFENSIVAS FINALIZADAS EM GOL

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Educação Física, para obtenção do título de *Magister Scientiae*.

VIÇOSA
MINAS GERAIS – BRASIL
2015

RODRIGO DE MIRANDA MONTEIRO SANTOS

PADRÕES DE COORDENAÇÃO INTERPESSOAL NO FUTEBOL: ANÁLISE DAS RELAÇÕES NUMÉRICAS RELATIVAS EM SEQUÊNCIAS OFENSIVAS FINALIZADAS EM GOL

Dissertação apresentada à Universidade Federal de Viçosa, como parte das exigências do Programa de Pós-Graduação em Educação Física, para obtenção do título de *Magister Scientiae*

APROVADA: 30 de junho de 2015.

José Guilherme Granja de Oliveira

Daniel Bruno Vieira Andrade Barreira

Ricardo Filipe Lima Duarte
(Coorientador)

Israel Teoldo da Costa
(Orientador)

Dedico à minha mãe e à minha tia Eliana, as maiores incentivadoras deste sonho.

Dedico aos alunos do Laboratório de Análise de Desempenho do NUPEF. Que este trabalho nos possa gerar novas oportunidades e ampliar nossos horizontes.

"Goodness is the only investment that never fails."

(Henry David Thoreau)

AGRADECIMENTOS

Agradeço à minha mãe pelo amor, apoio e carinho eternos e incondicionais. Em especial, por ter me acompanhado e me assistido nesta grande aventura que foi a Europa durante estes três meses.

À minha tia Eliana, por ter feito da minha felicidade e da dos meus irmãos, sua meta. Por ter tornado possíveis os sonhos mais ousados antes e durante esta etapa.

Aos meus avôs Clóvis e Monteiro, que sempre me serviram como modelo de hombridade, honestidade, bondade e luta.

À minha madrinha Simone, pelo carinho e hospitalidade, e por ser um exemplo de amor e dedicação à vida acadêmica.

À Tia Zilda, pelo infinito amor, paciência e dedicação.

Aos meus irmãos Felipe e Matheus, pelo companheirismo, cumplicidade e pelo amor que sentimos uns pelos outros.

Às minhas tias Daniela, Marina e Ludmila, pelo cuidado e carinho que sempre tiveram comigo. Meu amor por vocês é imensurável.

Ao meu pai, pelo modelo de retidão, disciplina e honestidade para mim e meus irmãos.

À minha irmã Carolina, por todos estes 21 anos em que compartilhamos as lutas de nossas mães, os encantos da nossa juventude e as responsabilidades da vida adulta.

À Rosane, pelo afeto maternal e sincero que sempre demonstrou por mim.

À Kalline, pelo amor, carinho, incentivo e cumplicidade durante tanto tempo.

Ao Geovani, pela amizade, cumplicidade e companheirismo.

À T.F. (Raul, Marcão, Piu-Piu, Jabá, Pedro, Rodolfo, Brunão, Thiaguinho, Miguel, Pretão e Bernardo), responsável por boa parte das melhores lembranças da minha juventude.

À Thaís, pelo companheirismo e apoio em muitos dos árduos períodos durante a realização deste trabalho.

À Luisa, pela preocupação e afeto que sempre demonstrou, e por me acolher e ouvir em muitos momentos difíceis.

À Dedé, pela amizade e cumplicidade.

Ao Fernando e à Ana Matos, pelo afeto, amizade e hospitalidade. Por nos fazerem sentir como uma parte da vossa família.

À Raquel, por tantas boas lembranças que guardo de Lisboa.

À Simone Oliveira, por todo o carinho e suporte durante o período em Lisboa.

À família Figueiredo Machado, pela hospitalidade e alegria com que nos receberam, e pelo carinho que sempre nutriram por mim.

Ao Maickel, pela cumplicidade e fidelidade com as quais sempre pude contar nos momentos de alegria e de angústia.

Ao Moniz, pela felicidade e afeto que sempre compartilhou conosco. Que a bondade que carrega consigo esteja também cada dia mais presente em cada um daqueles que gozam do privilégio da sua presença.

Ao Marcelo, pela humildade, sabedoria e respeito partilhados durante estes anos.

Ao Guilherme, pela amizade, carinho e alegria contagiante que possui.

Ao Adeilton, pela coragem e perseverança que sempre nos serviram de exemplo.

Ao Henrique Bueno, por sua amizade, pela ajuda na reta final deste trabalho e pelo companheirismo nesta grande empreitada que tem sido a estruturação do nosso Laboratório.

Ao Henrique Vianna, pelo suporte durante os primeiros passos do Laboratório de Análise de Desempenho do NUPEF.

Ao Elton, pela atenção e disponibilidade.

Ao Fernando e ao Bernardo, alunos do Laboratório de Análise de Desempenho do NUPEF, pelo interesse e dedicação ao nosso trabalho.

Ao Davi e João Vítor, pelas boas risadas e pelo companheirismo nestes dias de luta.

Ao Eder, pelos conselhos e atenção nas horas difíceis.

Ao Felippe, pelo apoio e atenção, e por sua dedicação ao NUPEF.

A todos os colegas do NUPEF, pelo esforço e dedicação diários. Os frutos da nossa luta e incansável busca pelo conhecimento certamente não tardarão.

Ao Alexandre Martins, pela paciência, disponibilidade e atenção quando da minha primeira visita à UFV.

Ao Cauan e ao Rafael Bagatin, amigos e colegas do Curso de Especialização em Futebol da UFV, pela paciência, compromisso e troca de conhecimentos.

À Júlia Zani, pelo exemplo de persistência, dedicação e amor ao Futebol.

Ao Toninho, Jurandy e à família PROESP.

Ao grande amigo Aluízio, pela amizade e parceria conservadas desde a graduação.

Ao Ben, Gemma e Milo por sua amizade e carinho.

Aos Professores Márcio Assis, Ricardo Abrantes e Celso Júnior, pela atenção e gentileza com que nos receberam e auxiliaram.

Ao Professor Leandro Fernandes Malloy-Diniz, por ter sido o grande incentivador dos meus primeiros passos na vida científica.

Ao Professor Varley Teoldo da Costa e ao Maurício José de Souza Filho, pela parceria e confiança no nosso trabalho.

A todos os funcionários do Departamento de Educação Física da Universidade Federal de Viçosa-MG.

À Faculdade de Motricidade Humana da Universidade de Lisboa.

À Faculdade de Desporto da Universidade do Porto.

Ao Lucas Mantovani, a quem nunca poderei agradecer suficientemente pela ajuda na realização deste trabalho. Tenha a certeza de que a sua dedicação e capacidade me serviram de incentivo para prosseguir nesta pesquisa, e de que estas mesmas qualidades o levarão longe.

Ao Matheus Berger, pela disponibilidade e atenção que devotou a este projeto.

Ao Carlos Miguel Dias, Bernardo Silva, Daniel Castelão e Ezequiel Müller, por me confiarem seus trabalhos, e também por partilharem seu conhecimento nos artigos desenvolvidos em conjunto.

Aos Professores Peter O'Donoghue e Lucy Holmes, da Cardiff Metropolitan University.

Ao Professor Keith Davids, da Sheffield Hallam University.

Ao Prof. Júlio Garganta, por dedicar seu tempo, conhecimento e experiência nas publicações conjuntas e por ter aceitado colaborar com este trabalho.

Ao Prof. Luís Vilar, pelo desenvolvimento do método que deu corpo a este trabalho, e também pelo subsequente interesse em contribuir para o seu aperfeiçoamento.

Ao Prof. Alexandre Brandão, do Departamento de Engenharia Elétrica da Universidade Federal de Viçosa, pela inestimável contribuição para que este trabalho se tornasse possível. Seu conhecimento, experiência e dedicação, bem como a seriedade com que tratou este projeto, foram essenciais para que pudéssemos materializá-lo.

Ao Prof. Ricardo Duarte, pela amizade, atenção, disponibilidade, e por ter partilhado comigo o seu conhecimento. Por ter ajudado a transformar meu período em Lisboa em uma grande e rica viagem ao "mundo" dos sistemas dinâmicos. Por ter me acompanhado e auxiliado nos momentos mais penosos durante a escrita deste trabalho.

Ao Prof. Israel Teoldo, pela confiança, conselhos, amizade, respeito, e também pela orientação neste trabalho. Por me ter proporcionado todas as condições para trabalhar e estar entre os melhores. Por ter me delegado a honrosa tarefa de conduzir o Laboratório de Análise de Desempenho do NUPEF, do qual sinto imenso orgulho em fazer parte.

Às agências de fomento que possibilitaram a realização deste trabalho: FAPEMIG, SETES através da LIE, CAPES, CNPq, FUNARBE, Reitoria, Pró-Reitoria de Pesquisa e Pós-Graduação e do Centro de Ciências Biológicas e da Saúde da Universidade Federal de Viçosa.

SUMÁRIO

RESUMO

SANTOS, Rodrigo de Miranda Monteiro, M.Sc., Universidade Federal de Viçosa, junho de 2015. **Padrões de coordenação interpessoal no Futebol: análise das relações numéricas relativas em sequências ofensivas finalizadas em gol.** Orientador: Israel Teoldo da Costa. Coorientador: Ricardo Filipe Lima Duarte

O objetivo deste trabalho foi verificar como a análise da coordenação interpessoal no futebol pode contribuir para a identificação de padrões de jogo emergentes a partir de sequências ofensivas finalizadas em gol. O documento está estruturado em três artigos científicos. O primeiro artigo destaca que o estudo da coordenação interpessoal no futebol vem se tornando um tópico de pesquisa emergente. Com o propósito de compreender como surge a coordenação entre jogadores e equipes, bem como identificar os padrões emergentes destas interações, diversos estudos têm investigado os diferentes níveis de interação (díades, subgrupos e equipes) que descrevem o jogo de futebol. Desta forma, os objetivos deste artigo foram: (i) fornecer uma breve descrição do *background* relativo aos conceitos que envolvem o tópico de *coordenação*; (ii) destacar os estudos e achados mais relevantes relativamente à investigação da coordenação interpessoal no futebol e (iii) discutir as implicações destes estudos e resultados o desenvolvimento de tarefas representativas em treino e pesquisa. Parece razoável sugerir que o desenvolvimento de tarefas representativas deve basear-se nos comportamentos e desempenhos observados em contextos reais de jogo. O segundo artigo objetivou a apresentação de uma nova ferramenta informática para análise de padrões de coordenação entre equipes de futebol a partir de imagens de vídeo. O instrumento inclui procedimentos objetivos e de baixo custo, em comparação aos caros e complexos sistemas de rastreamento automático disponíveis atualmente. Altos valores de fiabilidade indicam que esta ferramenta pode ser empregada em uma grande variedade de contextos no futebol e também em outros esportes coletivos. O terceiro artigo teve por objetivo identificar tendências de coordenação entre equipes a partir das sequências ofensivas finalizadas em gol da equipe campeã da Copa do Mundo FIFA® 2014. Foram analisados 6457 quadros de vídeo (unidade de análise) de 11 cenas de vídeo de sequências ofensivas finalizadas em gol. A incerteza das relações numéricas das equipes dentro das subáreas de jogo foi analisada em cada sequência ofensiva através da entropia de Shannon. Os valores de entropia indicaram que a incerteza das relações numéricas

das equipes foi maior na subárea Ofensiva Central da seleção alemã (subárea Defensiva Central adversária; 1,86 bits) em comparação ao restante das subáreas de jogo. Estes resultados sugerem que em sequências ofensivas finalizadas em gol, as relações numéricas relativas foram mais imprevisíveis na subárea do Espaço de Jogo Efetivo (EJE) mais próxima à baliza adversária. Futuros estudos devem verificar se este padrão é uma característica predominante em equipes bem sucedidas.

ABSTRACT

SANTOS, Rodrigo de Miranda Monteiro, M.Sc., Universidade Federal de Viçosa, June 2015. **Interpersonal coordination in Soccer: analysis of patterns of relative numerical relations in goal-scoring possessions.** Adviser: Israel Teoldo da Costa. Co-adviser: Ricardo Filipe Lima Duarte

The aim of this dissertation was to verify how the analysis of interpersonal coordination in soccer might contribute to the identification of emergent patterns of play in goal-scoring possessions in open play. The document comprises three scientific papers. The first paper highlights that the study of interpersonal coordination in soccer has recently become an emergent research topic. Several studies that have investigated the different levels of interactions (*dyads*, *sub-groups* and *teams*), which comprise soccer competition, aimed to comprehend how coordination between players and teams arises as well as to identify the emergent patterns from such interactions. Therefore, this leading article aimed: (i) to provide a brief description of the background regarding the main concepts within the topic of *coordination*; (ii) to highlight the most relevant studies and findings regarding the study of interpersonal coordination in soccer and (iii) to discuss the implications of these studies and findings for representative task design. It is reasonable to suggest that the design of representative tasks in training and testing should rely upon the performances and behaviours observed in actual match contexts. The purpose of the second paper is to present a novel computational tool to analyze inter-team coordination patterns in soccer from video footage. The paper describes the design of low-cost and straightforward manual tracking procedures in comparison with some expensive and highly complex automatic tracking systems currently available. High reliability values suggest that this tool can be employed in a great variety of contexts in soccer and other team sports. The third paper aimed to examine the emergent inter-team coordination tendencies from goal-scoring possessions in open play of the 2014 FIFA® World Cup winner team, through the analysis of teams' numerical relations within the effective play-space (EP-S). We assume that Germany generate more numerical uncertainty in sub-areas of play closer to opponents' goal in goal-scoring possessions. We analysed 6457 frames from 11 video sequences of goal-scoring possessions in open play during that tournament. Teams' numerical relations within sub-areas of play were examined in each offensive sequence through

Shannon's entropy, H. The uncertainty of numerical relationships between the teams across sub-areas was also calculated. Entropy measures indicated that the uncertainty of teams' numerical relations was higher within the German Central Offensive (opponents' Central Defensive) sub-area (1.86 bits) in comparison with the remaining sub-areas of play. These results confirm our initial hypothesis, displaying that, in goal-scoring possessions, the German team generates more numerical uncertainty in critical offensive sub-areas of play. Future research should verify whether such pattern is a predominant feature in successful teams.

GENERAL INTRODUCTION

1. Soccer match analysis

In soccer (association football), performance has been described as a construct comprised by several constituents and the interaction between them, both at the individual (player) and collective (team) levels (DRUST; ATKINSON; REILLY, 2007). Hence, the analysis of actions performed by players and teams in match context might generate relevant information to support scientific investigations and coaches' decisions with respect to the tactical, technical and physical aspects of the game (REILLY; THOMAS, 1976; POLLARD; REEP, 1997; CARLING; WILLIAMS; REILLY, 2005). However, despite the importance of these three aforementioned components to the game, investigations on match performance analysis in soccer have mostly aimed to describe only physical and technical aspects of this sport, thus not focusing on players' tactical behaviour and team organization (GARGANTA, 2009). Therefore, in order to contribute to a broader comprehension of the game and the contextual variables that influence the outcome of soccer contests, researchers and clubs staffs have, more recently, resorted to the analysis of the tactical component, so as to obtain more accurate information with respect to individual and collective performances that might be key to understand and shape players' and teams' behaviours (HUGHES; FRANKS, 2004).

Considering the tactical component, several analysis methods and tools have been developed and employed by a wide range of researchers with the purpose of identifying and studying patterns of play and their effectiveness. The study conducted by Reep and Benjamin (1968), who resorted to an observational approach and advanced statistical procedures, is one of the first that attempted to search for tendencies that led to goals or goal-scoring opportunities. The authors analysed the likelihood of passes and shots in key areas of the pitch that led to goals and/or goal-scoring opportunities in 101 professional soccer matches. Results indicated that 50% of the goals scored originated from passing sequences starting in the "shooting areas" (the two quarters of the pitch where the goals are located), whereas 15% of all passing sequences that reached these areas led to a shot at goal. Furthermore, findings displayed that 1 in every 10 shots lead to a goal and that shorter passing sequences led to more goals, in comparison to longer ones. Nevertheless, the statistical procedures and, as consequence, the results of this study, have been subject of criticism in literature, as they were thought to have led to misunderstandings, since the data regarding passing sequences were not normalized according to the frequency of their lengths, what would result in a contrasting interpretation of the results, given that when data are normalized, it was possible to observe that longer passing sequences generate more goals than shorter ones (HUGHES; FRANKS, 2005). Also, the findings and conclusions of the aforementioned investigation provided little, if any, practical applications, since the model employed rely upon the analysis of discrete events and employs statistical procedures that have little claim to generalizability.

Surprisingly, despite of the apparent lack of context of the variables investigated and the limited applicability of findings to training, research methods in soccer match analysis have undergone very few modifications for nearly 30 years after Reep and Benjamin's study (MACKENZIE; CUSHION, 2013). The investigations that followed have resorted to very similar approaches for identifying successful patterns of play or playing styles in order to distinguish performance profiles (BORRIE; JONES, 1998). In addition, a common issue regarding the identification of performance indicators is that the relationship between observed behaviour and outcome is often misinterpreted at the scientific level. Consequently, in order to account for significant comprehension of playing behaviour, metrics of soccer performance ought to clarify game outcomes (MCGARRY, 2009). Remarkably, investigations addressing such issues would not be conducted until the late 90s.

Nevertheless, by the end of the decade of 1990-2000 and in the early years of the decade of 2000-2010, researchers have started highlighting the importance of taking into account the dynamics of the game in order to obtain richer and applicable information about players' and teams' behaviours in the pitch (GRÉHAIGNE; BOUTHIER; DAVID, 1997; BORRIE; JONSSON; MANGNUSSON, 2002). Since then, the amount of work that employed the concepts of dynamic systems theory to analyse the complex interactions between players and teams within a match has increased significantly (DAVIDS; ARAÚJO; SHUTTLEWORTH, 2005; MCGARRY, 2005; DUARTE *et al.*, 2013). Therefore, while analytical methods of analysis try to decompose systems into as many constituents as possible, the systemic approach resorts to the view of the system as a whole, and thus aims to analyse the interactions of its parts/elements (WALLISER, 1977).

The dynamic systems theory is a concept that, unlike the analytical approach, enables researchers and coaches to collect and organize information with the purpose of generating more efficient behaviour in view of the dynamic characteristics of the game (e.g. consideration of opposing players, ball location, players' speed) (ATLAN, 1986; GRÉHAIGNE; BOUTHIER; DAVID, 1997; MCGARRY *et al.*, 2002). Hence, one of the core aspects that comprise the application of such theory within the context of soccer is the analysis of players' and teams' actions taking the opposition into account. Since the interactions between players (*interpersonal coordination*) and teams in a match were taken into account, the quality of research with respect to the identification of successful patterns of play has improved, since it provides a more contextualized interpretation of individual and collective behaviour (MCGARRY *et al.*, 2002; DUARTE; ARAÚJO; CORREIA*; et al.*, 2012; VILAR *et al.*, 2012). Therefore, in view of the importance of the study of interpersonal coordination between players and teams in soccer, several methods and tools have been developed to collect, analyse and interpret data through a more ecological and representative approach (FRENCKEN *et al.*, 2011; MOURA *et al.*, 2012; VILAR *et al.*, 2013). Some of the most prominent studies in soccer match performance analysis that resorted to the investigation of interpersonal coordination are described in the following topic.

2. Interpersonal coordination in soccer

Coordination between individuals (i.e. *interpersonal* coordination) plays a central role in most of daily situations and might be observed and analysed when people walk together, talk to each other or, from a more complex perspective, dance or play sports (SCHMIDT; CARELLO; TURVEY, 1990). Interpersonal coordination emerges from the joint coupling of the attractor dynamics that underpin the relative phasing of the coordinating structures (SCHMIDT; CARELLO; TURVEY, 1990). Correspondingly, in sports sciences, a considerable body of work has indicated that in regard to (individual and team) sports contests, athletes' behaviours are to be observed and understood in the light of the same principles (MCGARRY; FRANKS, 1996; GRÉHAIGNE; BOUTHIER; DAVID, 1997; BOURBOUSSON; SÉVE; MCGARRY, 2010). In view of such principles, individual sports encompass inter-coupling between two opponents, whereas team sports incorporate several dyads that combine to engender intra- and inter-team couplings (BOURBOUSSON; SÉVE;

MCGARRY, 2010). Thus, team sports performance is better described as being an outcome of the relations between players and teams and, as a consequence, such interactions need to be considered as being inseparable, if one is to analyse match behaviours (BOURBOUSSON; SÉVE; MCGARRY, 2010).

Therefore, in order to observe and describe the complex interactions between opposing players and teams, most of the research that investigated patterns of coordination between players and teams published thus far, largely did so by taking into account the levels of analysis (couplings and couplings of couplings). In the study of interpersonal coordination in team sports, such levels of interactions between system's components are classified as *dyads* (one vs. one) and *collectives* (many vs. many). This perspective assumes that all players are elements that oscillate around a mutual locus, and is based on the assumption that *team vs. team* interactions encompass numerous *one vs. one* interactions (MCGARRY, 2005) that are able to shape synergies at sub-group and team levels. Hence, with the purpose of understanding how coordination between players and teams emerges, as well as of identifying the patterns that arise from these given interactions, several studies have analysed the different levels of interactions (*dyads*, *sub-groups* and *teams*) that involve soccer competition.

Yet, research on interpersonal coordination in soccer has mainly focused on the spatiotemporal patterns in 1vs.1 sub phases. Investigations have analysed the way the player in possession breaks symmetry in relation to a defender so as to achieve a penetrating pass or a shot (DUARTE; ARAÚJO*; et al.*, 2012b; CLEMENTE *et al.*, 2013; ORTH *et al.*, 2014a). Hence, it is possible to affirm that relying on the analysis of dyads is a somehow limited approach, since the interactions between players and teammates plays a crucial role for decision making. However, investigations exceed the dyadic level or that analyse players' interactions in competitive matches are apparently limited (FRENCKEN *et al.*, 2012). Taking this limitation into consideration, Vilar et al. (2013) proposed a novel approach to analyse the way teams occupy sub-areas of the field based upon the hypothesis that numerical advantage is vital for the creation of scoring opportunities and defensive stability. This approach was employed within the present study, with the purpose of identifying patterns of numerical relations in goal-scoring possessions in open-play, and will be discussed within the next chapters.

3. Goal-scoring patterns

Goal scoring is regarded as being the ultimate indicator of offensive success in soccer (BATE, 1988; POLLARD; REEP, 1997). Since the analysis of actions that lead to goals and/or goal-scoring opportunities allows coaches and match analysts to identify and employ the most effective playing methods in order to score and avoid conceding goals, it has drawn the attention of a fair amount of sports scientists (HUGHES; FRANKS, 2005; REDWOOD-BROWN, 2008).

One of the first investigations on goal-scoring plays was conducted by Reep and Benjamin (1968), whose results indicated that approximately 80% of the goals emerged from sequences of three or less passes. Also, the authors reported that 1 out of 10 shooting attempts would lead to a goal. However, Hughes and Franks (2005) suggested that the data reported by the aforementioned study were not normalized and therefore indicated that such findings could lead to misinterpretations. Yiannakos and Armatas (2006) verified that 44.1% of the goals in the UEFA® Euro 2004 were scored through organized attacks, whilst only 20.3% were scored through counterattacks. In addition, results displayed that 63.4% of the goals in this tournament were scored through long passes and combination plays, whereas 17.1% were scored through individual actions. In a recent study, Tenga et al. (2010) indicated that counterattacks (13.4%) lead to more goals when compared to elaborate attacks (8.8%). Correspondingly, long possessions (14.4%), mixed passing length (12.5%) and penetrative passes (25.4%) displayed higher probability of creating goals than short possessions (7.6%), long passes (2.6%) and non-penetrative passes (1.4%), respectively. Yet, while these investigations provide significant information with respect to the emergent patterns in goal-scoring possessions, regarding their methodological approach and study design authors give little if any attention to the inter-team tendencies that trigger the actions in these plays.

Therefore, resorting to the study of interpersonal coordination with the purpose of capturing and describing patterns that emerge from the interactions between teammates and opponents is an approach that most certainly provides more relevant and useful information to researchers and coaches, in comparison to traditional data analysis methods (MCGARRY, 2009; VILAR *et al.*, 2012).

Thus, with the purpose of detecting and analysing such numerical relationships as well as their emergent patterns, Vilar et al. (2013) proposed a novel method to examine how teams occupy sub-areas of play. Through this approach, the authors analysed a soccer match based upon the hypothesis that local player numerical dominance is critical for defensive stability and offensive opportunity. Such method is described in detail in papers 2 and 3 within the present dissertation and might contribute significantly to the study of emergent coordination patterns from goal-scoring possessions.

OBJECTIVES

General

The purpose of this study is to verify whether the study of interpersonal coordination in soccer, more specifically through the analysis of inter-team relative numerical relations, is likely to contribute to the identification of emergent patterns of play in goal-scoring possessions in open play.

Specific

Describe the most important studies on interpersonal coordination in soccer, thus highlighting the implications of their findings to research and practice in match performance analysis;

Introduce a novel, low-cost and straightforward tool for the analysis of inter-team coordination from video footage;

Examine the emergence of inter-team numerical relations from open-play goal-scoring possessions of the German National Soccer Team.

DISSERTATION STRUCTURE

This dissertation is arranged according to the model proposed by the norms of presentation of dissertations and theses from the Universidade Federal de Viçosa comprised by scientific papers submitted for publication to indexed journals. This format allows the presentation of the papers developed during the process.

The structure of this study includes an introduction chapter, which includes a brief literature review on the topics being addressed, as well as the relevance of this research and its objectives. In the following chapter, the investigations conducted are presented as follows:

The first paper, entitled "Interpersonal Coordination in Soccer: Overview and Implications for Representative Task Design", aims to provide a brief description of the background concerning the main concepts within the topic of *coordination*; (ii) to highlight the most relevant studies and findings regarding the study of interpersonal coordination in soccer and (iii) to discuss the implications of such studies and findings for researchers and practitioners in match performance analysis.

The second paper - "Design and reliability of a computational tool to analyze inter-team coordination patterns in soccer from video footage" - aims to present a novel computational tool to analyze inter-team coordination patterns in soccer from video footage.

The third paper, entitled "Inter-team coordination tendencies of goal-scoring possessions in open play: an analysis of the 2014 FIFA® World Cup winner team" aims to examine the emergent inter-team coordination tendencies from goal-scoring possessions in open play of the 2014 FIFA® World Cup winner team, through the analysis of teams' numerical relations within the effective play-space.

Following the presentation of the papers, the general concluding remarks are addressed.

REFERENCES

ATLAN, H. **Entre le cristal et la fumée**. Paris: Seuil. 1986. 285 p.

BATE, R. Football chance: tactics and strategy. In: T. Reilly, A. Lees, K. Davids e W. J. Murphy (Ed.). **Science and Football: Proceedings of first World Congress of Science and Football**. London: E. & F. N. Spon Ltd, 1988, p.293-301.

BORRIE, A.; JONES, K. It's not what you do it's the way that you do it: is frequency of occurrence and adequate index of performance in observational analysis? **Journal of Sports Sciences**, v.16, n.1, p.14. 1998.

BORRIE, A.; JONSSON, G. K.; MANGNUSSON, M. S. Temporal pattern analysis and its applicability in sport: an explanation and exemplar data. **Journal of Sports Sciences**, v.20, n.10, p.845-52. 2002.

BOURBOUSSON, J.; SÉVE, C.; MCGARRY, T. Space-time coordination dynamics in basketball: Part 1. Intra- and inter-couplings among player dyads. **Journal of Sports Sciences**, v.28, n.3, p.339-47. 2010.

CARLING, C.; WILLIAMS, A. M.; REILLY, T. **Handbook of Soccer Match Analysis**. New York: Routledge. 2005.

CLEMENTE, F. M.; COUCEIRO, M. S.; MARTINS, F. M. L.; DIAS, G.; MENDES, R. Interpersonal Dynamics: 1v1 Sub-Phase at Sub-18 Football Players. **Journal of Human Kinetics**, v.36, p.181-91. 2013.

DAVIDS, K.; ARAÚJO, D.; SHUTTLEWORTH, R. Applications of Dynamical Systems Theory to Football. In: T. Reilly, J. Cabri e D. Araújo (Ed.). **Science and Football V: The Proceedings of the Fifth World Congress on Science and Football**. Oxon, UK: Routledge, 2005, p.537-50.

DRUST, B.; ATKINSON, G.; REILLY, T. Future Perspectives in the Evaluation of the Physiological Demands of Soccer. **Sports Medicine**, v.37, n.9, p.783-805. 2007.

DUARTE, R.; ARAÚJO, D.; CORREIA, V.; DAVIDS, K. Sports Teams as Superorganisms. **Sports Medicine**, v.42, n.8, p.633-42. 2012a.

DUARTE, R.; ARAÚJO, D.; CORREIA, V.; DAVIDS, K.; MARQUES, P.; RICHARDSON, M. J. Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. **Human Movement Science**, v.32, n.4, p.555-66. 2013.

DUARTE, R.; ARAÚJO, D.; DAVIDS, K.; TRAVASSOS, B.; GAZIMBA, V.; SAMPAIO, J. Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes in youth soccer. **Journal of Sports Sciences**, v.30, n.9, p.871-7. 2012b.

FRENCKEN, W.; DE POEL, H.; VISSCHER, C.; LEMMINK, K. Variability of inter-team distances associated with match events in elite-standard soccer. **Journal of Sports Sciences**, v.30, n.12, p.1207-13. 2012.

FRENCKEN, W.; LEMMINK, K.; DELLEMAN, N.; VISSCHER, C. Oscillations of centroid position and surface area of soccer teams in small-sided games. **European Journal of Sport Science**, v.11, n.4, p.215-23. 2011.

GARGANTA, J. Trends of tactical performance analysis in team sports: bridging the gap between research, training and competition. **Revista Portuguesa de Ciências do Desporto**, v.9, n.1, p.81-9. 2009.

GRÉHAIGNE, J.-F.; BOUTHIER, D.; DAVID, B. Dynamic-system analysis of opponent relationships in collective actions in soccer. **Journal of Sports Sciences**, v.15, n.2, p.137-49. 1997.

HUGHES, M.; FRANKS, I. Analysis of passing sequences, shots and goals in soccer. **Journal of Sports Sciences**, v.23, n.5, maio, p.509–14. 2005.

HUGHES, M.; FRANKS, I. M. **Notational Analysis of Sport**. New York: Routledge. 2004. 304 p.

MACKENZIE, R.; CUSHION, C. Performance analysis in football: A critical review and implications for future research. **Journal of Sports Sciences**, v.31, n.6, p.639-76. 2013.

MCGARRY, T. Soccer as a Dynamical System: Some Theoretical Considerations. In: T. Reilly, J. Cabri e D. Araújo (Ed.). **Science and Football V: The Proceedings of the Fifth World Congress on Science and Football**. Oxon, UK: Routledge, 2005, p.551-60.

______. Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. **International Journal of Perfomance Analysis in Sport**, v.9, n.1, p.128-40. 2009.

MCGARRY, T.; ANDERSON, D. I.; WALLACE, S. A.; HUGHES, M. D.; FRANKS, I. M. Sport competition as a dynamical self-organizing system. **Journal of Sports Sciences**, v.20, n.10, p.771-81. 2002.

MCGARRY, T.; FRANKS, I. In search of invariant athletic behaviour in competitive sport systems: An example from championship squash match-play. **Journal of Sports Sciences**, v.14, n.5, p.445-56. 1996.

MOURA, F. A.; MARTINS, L. E. B.; ANIDO, R. O.; BARROS, R. M. L.; CUNHA, S. A. Quantitative analysis of Brazilian football players' organisation on the pitch. **Sports Biomechanics**, v.11, n.1, p.85-96. 2012.

ORTH, D.; DAVIDS, K.; ARAÚJO, D.; RENSHAW, I.; PASSOS, P. Effects of a defender on run-up velocity and ball speed when crossing a football. **European Journal of Sport Science**, v.14, n.Sup. 1. 2014.

POLLARD, R.; REEP, C. Measuring the effectiveness of playing strategies at soccer. **The Statistician**, v.46, n.4, p.541-50. 1997.

REDWOOD-BROWN, A. Passing patterns before and after goal scoring in FA Premier League Soccer. **International Journal of Perfomance Analysis in Sport**, v.8, n.3, p.172-82. 2008.

REEP, C.; BENJAMIN, B. Skill and Chance in Association Football. **Journal of the Royal Statistical Society**, v.131, n.4, p.581-5. 1968.

REILLY, T.; THOMAS, V. A Motion Analysis of Work-Rate in Different Positional Roles in Professional Football Match-Play. **Journal of Human Movement Studies**, n.2, p.87-97. 1976.

SCHMIDT, R. C.; CARELLO, C.; TURVEY, M. T. Phase Transitions and Critical Fluctuations in the Visual Coordination of Rhythmic Movements Between People. **Journal of Experimental Psychology: Human Perception and Performance**, v.16, n.2, p.227-47. 1990.

TENGA, A.; HOLME, I.; RONGLAN, L. T.; BAHR, R. Effect of playing tactics on goal scoring in Norwegian professional soccer. **Journal of Sports Sciences**, v.28, n.3, p.237-44. 2010.

VILAR, L.; ARAÚJO, D.; DAVIDS, K.; BAR-YAM, Y. Science of winning soccer: emergent pattern-forming dynamics in association football. **Journal of Systems Science and Complexity**, v.26, n.1, p.73-84. 2013.

VILAR, L.; ARAÚJO, D.; DAVIDS, K.; BUTTON, C. The Role of Ecological Dynamics in Analysing Performance in Team Sports. **Sports Medicine**, v.42, n.1, p.1-10. 2012.

WALLISER, B. **Systèmes et modèles: Introduction critique à l'analyse de systèmes**. Paris: Éditions du Seuil. 1977. 256 p.

YIANNAKOS, A.; ARMATAS, V. Evaluation of the goal scoring patterns in European Championship in Portugal 2004. **International Journal of Perfomance Analysis in Sport**, v.6, n.1, p.178-88. 2006.

PAPER 1

Title: Interpersonal Coordination in Soccer: Overview and Implications for Representative Task Design

Rodrigo Santos, Ricardo Duarte, Keith Davids, Júlio Garganta and Israel Teoldo

Abstract: Dynamic systems theory encompasses several characteristics that are important for the investigation of interaction processes in sports. Hence, the study of interpersonal coordination in soccer has recently become an emergent research topic. With the purpose of understanding how coordination between players and teams arises, as well as of identifying the patterns that emerge from these given interactions, several studies have investigated the different levels of interactions (*dyads*, *sub-groups* and *teams*) that comprise soccer competition. Therefore, the aims of this leading article are threefold: (i) to provide a brief description of the background concerning the main concepts within the topic of *coordination*; (ii) to highlight the most relevant studies and findings regarding the study of interpersonal coordination in soccer and (iii) to discuss the implications of these studies and their findings for the design of representative tasks. It is reasonable to suggest that the design of representative tasks with the utilization of sub-phases of the game (1 vs. 1, many vs. many) should rely upon players' behaviours and performances in actual match settings (11 vs. 11).

Keywords: Interpersonal coordination; soccer; dyads; sub-groups; teams.

1 Introduction

Dynamic systems theory display several signature characteristics that are relevant for the investigation of interaction processes in sports (DAVIDS; ARAÚJO; SHUTTLEWORTH, 2005). For example, the analysis of team sports performance by adopting a dynamic systems approach has attempted to clarify how coordinated interactions between players/teams and features of a performance environment emerges (VILAR *et al.*, 2012). Hence, the study of interpersonal coordination patterns in team sports, and more particularly in soccer, has recently become an emergent research topic in sports sciences. Since the number of studies that have investigated patterns of coordination in soccer has significantly increased, it is important to elucidate the key concepts explaining dynamical interactions of players, and highlight the most relevant findings of the growing body of work on interpersonal coordination in soccer.

Therefore, the aims of this leading article are threefold: (i) to provide a brief description of the background concerning the main concepts within the topic of *interpersonal coordination*; (ii) to highlight the most relevant studies and findings regarding the study of interpersonal coordination in soccer; and (iii), to discuss the implications of such studies and their findings for representative experimental design.

2 From *intra*- to *inter*-personal coordination

Over the years, several branches of science have characterized *coordination* by employing this term to outline processes that are specific to their respective fields of knowledge. In animal physiology, for example, it is considered "the processes involved in the reception of sensory information, the integration of that information, and the subsequent response of the organism" (MARTIN; HINE, 2008). On the subject of motor control, Bernstein (BERNSTEIN, 1967) defined *coordination* as "the organization of the control of the motor apparatus" (TURVEY, 1990). From such definitions, *coordination* can be described in microscopic terms, such as the processing activities of the nervous system in order to acquire sensory information, or from a macroscopic point of view, regarding the continuous (re) organisation of body parts and limb segments during movements (TURVEY, 1990). Limb movements are often categorized in two scales: *intra*- and *inter*-limb coordination.

Intra-limb coordination deals with the questions that comprise the specific principles of movement of individual segments of a limb in relation to each other (SCHAAL, 2002). Inter-limb coordination is described as a "means of studying how the same or different anatomical components are put together to perform coordinated functions" (FUCHS; KELSO, 1994; SEIFERT *et al.*, 2013). Kelso (KELSO, 1995) refers that investigating the dynamics of pattern formation in such complex adaptive systems is worthwhile, since they comprise a great number of mechanisms to be coordinated and, therefore, are likely to generate a considerable number of patterns, especially in harnessing system degeneracy (SEIFERT *et al.*, 2014). Therefore, both scales of analysis described above comprise the *intrapersonal* level of coordination.

With respect to the question about whether the features observed in intrapersonal coordination are also applicable for the analysis of the individual-environment coordination (SCHMIDT; CARELLO; TURVEY, 1990; FUCHS; KELSO, 1994), Schmidt and colleagues reported that the principles underlying intrapersonal coordination also account for the investigation of interactions between individuals (SCHMIDT; CARELLO; TURVEY, 1990). Also, (SCHMIDT; O'BRIEN; SYSKO, 1999) suggested that interpersonal coordination should be understood based upon the idea of self-organization, defined as the processes that generate order and structure within a system. Hence, the proposed theoretical framework reveals that interpersonal coordination does not emerge uniquely from the cognitive or neural constitution of such individuals, but rather from the fashion in which organisms fit together (i.e. natural patterns). Furthermore, patterns emerging from interpersonal structures are to be described by the same characteristics commonly observed in natural settings and there is some evidence that interpersonal coordination can emerge in a sub-conscious manner, even at an elite level of athletic performance (STEVENS, 1976; VARLET; RICHARDSON, 2015).

In short, interpersonal coordination arises due to the joint coupling of the attractor dynamics that underpin the relative phasing of the coordinating structures in human movement systems and between athletes in a team performance context (SCHMIDT; CARELLO; TURVEY, 1990). Indeed, Kelso suggested that this principle of universality for complex adaptive systems reveals that such systems comply with analogous characteristics with respect to their different scales of analysis (KELSO, 1995). This is an important idea to guide performance analysis in sport science. Accordingly, within the sports sciences, a considerable amount of investigation has indicated that with regard to individual and team sports contests, athletes' behaviours need to be observed and understood in light of the same principles (MCGARRY; FRANKS, 1996; GRÉHAIGNE; BOUTHIER; DAVID, 1997; BOURBOUSSON; SÉVE; MCGARRY, 2010). In view of such principles, individual sports encompass inter-individual coupling between two opponents or between an athlete and an object in the environment, whereas team sports reveal how individual system components, such as competing players can entrain the behaviour of the whole complex system in team games, incorporating one or several dyads that combine intra- and inter-team couplings (BOURBOUSSON; SÉVE; MCGARRY, 2010).

Correspondingly, the coupling interactions between oscillating elements in a collective system yields dynamical characteristics that describe interactions in sports teams (MCGARRY *et al.*, 2002; MCGARRY, 2005). Thus, team sports competition (e.g. basketball, rugby union and soccer) is likely to display both competitive and cooperative characteristics. Consequently, every player within a team coordinates his/her actions with teammates in search of a joint objective during a match. In turn, opposing players and teams must coordinate their actions between each other, in an attempt to create scoring opportunities for their respective sides and to prevent the opposition from scoring (MCGARRY *et al.*, 2002; GLAZIER, 2010). Therefore, in team sports, the investigation of players' and teams' performances should not be restricted to analyses that do not consider the influence of opposition on individual and collective actions (DUARTE; ARAÚJO; CORREIA*; et al.*, 2012). Hence, performance in team sports is better understood as an outcome of the relations between players and teams and, as a consequence, such interactions need to be considered inextricable, if one is to analyse match behaviours (BOURBOUSSON; SÉVE; MCGARRY, 2010).

In order to observe and describe the complex interactions between opposing players and teams, most of the research that has investigated patterns of coordination between players and teams published thus far has largely employed different levels of analysis (couplings and couplings of couplings). In the study of interpersonal coordination in team sports, such types of interactions among system's components are categorized as *dyads* (one vs. one) and *collectives* (many vs. many). This perspective defines all players as elements that oscillate around a mutual locus, and is based on the assumption that *team vs. team* interactions involve numerous *one vs. one* interactions (MCGARRY, 2005) that are able to shape synergies at sub-group and team levels. The study of *synergies* aims to investigate the fundamental collective variables of a system, based on the assumption that, in critical situations, such systems are controlled by a limited number of degrees of freedom, thus uncovering the existence of an attractor and, consequently, resulting in a significant decrease in complexity (HAKEN, 1977; KELSO; SCHÖNER, 1988). Hence, the acting constraints that indicate how a system's degrees of freedom might become reciprocally dependent were defined by (BERNSTEIN, 1967) as *coordinative structures* (DAVIDS; ARAÚJO; SHUTTLEWORTH, 2005).

3 Interpersonal Coordination in Soccer

Soccer (association football) is a tactical sport, and thus demands from coaches, performance analysts and researchers an appropriate level of comprehension on the coordination processes between its individual elements (e.g. players) during performance (DAVIDS; ARAÚJO; SHUTTLEWORTH, 2005). Competitive soccer can be described as systems whose interacting elements generate a large amount of varied patterns at a macro-level, which differ from the behaviour of each element examined in isolation at a micro-level. Hence, the structures and patterns that comprise a soccer match should be contemplated in their entirety, rather than being analysed in a fragmented fashion (GRÉHAIGNE; BOUTHIER; DAVID, 1997).

For this reason, with the purpose of understanding how coordination between players and teams arises, as well as of identifying the patterns that emerge from these given interactions, several studies have investigated the different levels of interactions at various sub-phases (between *dyads* - in 1v1 situations - *sub-groups* - attacking and defending units of players - and full *teams*) that encompass soccer competition. Next we examine important studies that characterize such levels of interactions in soccer.

3.1 Dyads

Dyads (player-player interactions) comprise the elementary unit of analysis to the study of patterns of coordination in sports contests. Also, the relations between two opposing players in competitive matches have been considered essential to support the analysis of playing performance (MCGARRY, 2009). Through this perspective, a considerable amount of research has been carried out in order to identify emergent patterns of coordination from attacker-defender dyads in team games, including soccer.

Original research almost a decade ago revealed that a key feature of successful performance in team sports is the need for athletes to learn how to interact with teammates and opposing players to achieve their task goals (PASSOS; DAVIDS, 2015). This process of continuous interaction is founded on players' co-adaptive behaviours, which are constrained by locally created information. This information emerges from different task constraints, including field markings and boundaries and rules, all influenced by changes in relative positioning of teammates and opponents. However, while field boundaries and rules remain unchanged during competitive performance, players' relative positioning over the timescale of performance is a key variable that continuously alters due to the location and presence of significant others. For example, early research in team sport dyads revealed the importance of the interaction between key performance variables, which were high in predictive value, such as interpersonal distance between competing players and relative velocity of the players (for a review see (PASSOS; DAVIDS, 2015)). One of the first studies that analysed dyads in soccer was conducted by (ORTH *et al.*, 2014b) and evaluated the effects of defensive pressure on running velocity in footballers during the approach to kick a stationary football. Approach velocity and ball speed/accuracy data were recorded from eight youth players (aged 15.25, SD = 0.46 years). They were observed as they ran towards a football to cross it to a receiver in the penalty area to try and score against a goalkeeper. Defensive pressure was manipulated in three counterbalanced conditions: no defender present; a defender located far away and defender located nearer. The results revealed how players subtly altered their performance under changing task constraints without specific instructions from the experimenters. For example, ball speed of the cross was significantly reduced as defensive pressure was increased. Locating defender starting positions closer to the start position of the attacker significantly increased average running velocity. In footfalls during the final approach to the ball approach velocity was dependent on both presence and initial distance of a defender as a key task constraint. Despite these changes to movement organisation, passing accuracy was maintained under changing defensive pressure by the skilled developing footballers. Overall, the results implied that the regulation of kicking behaviours is specific to a performance context and that some features of movement organisation will not actually emerge unless the presence of a defender is manipulated as a task constraint during practice in soccer. Another study of dyadic systems in soccer by (HEADRICK *et al.*, 2012) examined how location onfield constrained movement regulation of players. They sought to determine whether spatiotemporal relations between players and the ball in 1vs.1 interactions were constrained by their distance to the goal area. The experiment consisted of each participant performing the role of attacker (player in possession) and defender in settings designed to simulate actual match situations. It was found that modifying the distance to goal of 1vs.1 dyads influenced players' behaviours and intentionality in relation to the ball. Specifically, they suggested that the variable "defender-to-ball distance" might be considered a critical dyadic system performance variable, since the percentage of successful trials for the player in possession revealed higher success rates for field positions located closer to goal.

Also by employing match-simulated environmental settings, Duarte and colleagues examined the influence of interpersonal coordination tendencies on performance outcomes (creation of shooting opportunities by the attacker or ball recovery by the defender) of 1vs.1 sub-phases in U-12 soccer players (DUARTE; ARAÚJO*; et al.*, 2012a). Results displayed high-level spatiotemporal synchronization between players in successful outcomes for attackers, while defenders' ability to perform effective moves that preceded the attackers' moves was identified as key to ball recovery by a player. In short, defenders' success was associated with increased time delays, whereas attackers evidenced higher success rates when a tight coupling with the defender was created (therefore providing defenders with less time to react to a dribbling move).

3.2 Sub-groups

Dyadic interactions comprise the most basic level of the match system. Hence, the analysis of more complex sub-phases has become relevant for understanding coordination among sub-groups of players (MCGARRY *et al.*, 2002;

DUARTE; ARAÚJO; CORREIA*; et al.*, 2012). An early study which examined interactions between players in sub-phases of sports teams was conducted by (PASSOS *et al.*, 2011). They showed that distance to a defensive line in team sports shaped the interpersonal distance between players in an attacking sub-unit. As in the studies of Orth et al. and Headrick et al. discussed above, this co-adaptive behaviour between attacking players was *emergent* since no specific instructions were provided to participants observed during performance in a practice sub-phase. These findings suggested that, since small-sided games (SSGs) can be considered to provide a sublevel of a match system, they could be employed as a means to examine interpersonal coordination patterns in soccer.

With the aim of investigating collective behaviour patterns in 3vs.3 sub-phases of play in contexts of creation and prevention of goal-scoring opportunities, (DUARTE; ARAÚJO; FREIRE*; et al.*, 2012) identified coordination tendencies in each team in a 3vs.3 SSG, by using centroid (i.e. average team position) and surface area (i.e. occupied space) measures, obtained through manual video tracking procedures and 2-D reconstruction (DUARTE *et al.*, 2010). They reported that the centroids of both teams approached and moved away from each other's defensive line in a very tied (ebbing and flowing) manner, particularly at the moments that preceded the 3v3 systems' loss of stability (i.e. during performance of passes that assisted goal attempts). These findings suggest that the two sub-groups moved synchronously in relation to each other. The emergence of such characteristics was attributed to a prominent degree in the distance between the attacking team and the defensive line (DUARTE; ARAÚJO; FREIRE*; et al.*, 2012). On the other hand, the surface area did not reveal the existence of clear patterns of coordination between the teams. Thus, the fact that the surface area was not able to uncover coordination patterns between sub-groups could not be transferrable to full-sided game contexts, since quick changes in this variable might be due to rapid exchanges in ball possession in the 3v3 context (DUARTE; ARAÚJO; FREIRE*; et al.*, 2012). The outcomes of this study provided relevant tactical information by uncovering how sub-groups of opposing players deal with each other within high-risk areas of the pitch (near the scoring zones on field).

Likewise, (FRENCKEN *et al.*, 2011) aimed to identify emergent playing patterns in SSGSs (4vs.4) through the use of centroid positions and surface area measures, acquired by positional data that were obtained through a transponder and antennas placed in a vest worn by each player during performance (FRENCKEN; LEMMINK; DELLEMAN, 2010). Results confirmed their hypothesis that teams' centroids display a tendency to move towards the same directions during a competitive game. Also, findings revealed the existence of a stronger association for centroids' forward-backward oscillations in relation to lateral oscillations. Nonetheless, as also shown by (DUARTE; ARAÚJO; FREIRE*; et al.*, 2012), Frencken and colleagues did not observe any linear associations between teams' surface areas. They attributed this outcome to the type of SSGSs that comprised the experimental task (FRENCKEN *et al.*, 2011). There is a need for more analyses of teams' surface areas to be examined in full-sided 11vs.11 games, instead of SSGSs, since this sub-phase of play apparently was not able to reveal the importance of such a variable for identifying coordination patterns in soccer.

3.3 Teams

Since the investigation of coordination patterns has often been analysed through the perspective of 1vs.1 situations (dyads) or small-sided games (sub-groups), the degree to which the tendencies observed at such scales of analysis could reliably describe actual match dynamics is still somewhat uncertain (BARTLETT *et al.*, 2012). However, some important studies have been conducted in order to verify whether these patterns could also characterize interactive patterns in full-sided games.

For example, (FRENCKEN *et al.*, 2012) aimed to examine whether inter-team distance would relate to match events by analysing variability of longitudinal and lateral distances between teams, which were defined by them as the (longitudinal and lateral) difference between teams' centroids. Findings suggested that inter-team distances were only marginally related to match situations, although acute stages of a match that emerged from fluctuations in lengthwise direction were reported to be associated with players' movement patterns following longitudinal and lateral passes. This observation suggests that highly variable periods in inter-team distance values are associated with both longitudinal and lateral passes. It appears that all match situations analysed were dependent on the direction of play and relative position of the ball (FRENCKEN *et al.*, 2012).

Also with respect to the variability of inter-team coordination, (VILAR *et al.*, 2013) introduced a novel approach to the analysis of emergent functional-structural patterns in soccer, based on the assumption that numerical advantage plays an essential role in defensive stability and creation of goal-scoring opportunities. They analysed the uncertainty of teams' numerical relations in sub-areas of play (see Fig. 1) within the effective-play space (EP-S). The EP-S is defined by (GRÉHAIGNE; MAHUT; FERNANDEZ, 2001) as the polygonal area encompassing the imaginary line that links all outfield players located at the periphery of play at a given instant. Analyses were performed considering the numerical relations of the opposing teams based on the numerical relations within opposing sub-areas of play. In addition, the

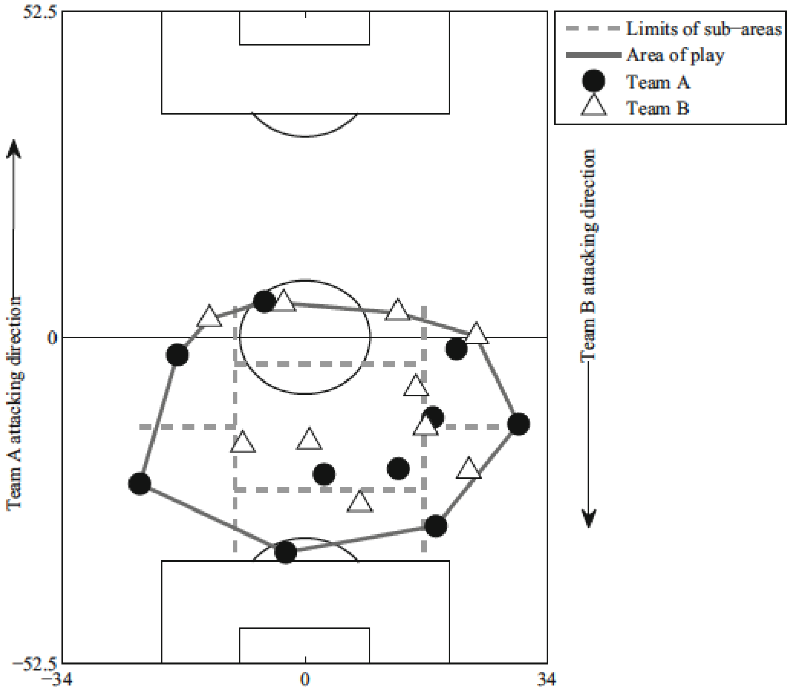

Fig. 1. Sub-areas of play within the effective play-space (EP-S) [30].

uncertainty of such numerical relations across sub-areas of play was calculated through the utilization of Shannon's entropy, *H* (SHANNON, 1948). The main findings revealed that in sub-areas of play closer to opponent's goal, the teams seldom allocated more players than the opposition. Moreover, entropy measures revealed that the central midfield sub-area of play is highly unpredictable with respect to numerical relations between the teams. Therefore, this outcome confirms, through an ecological perspective, a tactical aspect of the game that has already been hypothesized by traditional notational studies, which were not able to capture such dynamics by means of typical analytical measures.

4 Implications for representative task design

The purpose of soccer research is to provide coaches with relevant information with respect to the performance of players and teams, so as to allow the transfer of knowledge from the experimental setting to actual environments (CARLING; WILLIAMS; REILLY, 2005). In order to achieve such purpose, a proper level of representativeness of the tasks performed by participants in training or experimental settings is required if this knowledge is to be put to use with the aim of enhancing individual and collective performances in match context (PINDER *et al.*, 2011).

In that respect, coordination data obtained during actual match contexts might provide proper resources for the assessment of action fidelity of simulated training and learning environments, the aim of action fidelity being to verify whether players' decisions and actions are similar in two distinct circumstances, when one attempts to replicate performance settings in experimental environments (ARAÚJO; DAVIDS; PASSOS, 2007). The implications of this line of reasoning suggest that drills or test trials that do not take into account the representative design of performance settings might hamper the accurate assessment of essential performance features that demand training or improvement, and also the progress of training intervention and training drills that support the development of such aspects (PINDER *et al.*, 2011).

Therefore, small-sided (1v1, 3v3, etc.) experimental practice tasks should consider the performance observed in actual match (or 11v11) settings, in order to enable researchers to generalize findings and conclusions to broader contexts, as well as to allow coaches to develop and conduct training drills that more accurately simulate real game situations (ARAÚJO; DAVIDS; PASSOS, 2007; TRAVASSOS *et al.*, 2012). Hence, since an important subject related to the design of learning environments regards the representation of the stimuli available in competitive performance, it seems reasonable to suggest that the development and execution of experimental tasks that involve sub-phases of the game should rely on the behaviours and performances observed during real soccer contests (PASSOS; DAVIDS, 2015).

Acknowledgements

This study was funded by the State Department of Tourism and Sport of Minas Gerais (SETES-MG) through the State Act of Incentive to Sports, by

FAPEMIG, CAPES, CNPQ, FUNARBE, the Dean's Office for Graduate and Research Studies and the Centre of Life and Health Sciences from the Universidade Federal de Viçosa, Brazil.

References

1. Davids K, Araújo D, Shuttleworth R. Applications of Dynamical Systems Theory to Football. In: Reilly T, Cabri J, Araújo D, editors. Science and Football V: The Proceedings of the Fifth World Congress on Science and Football. Oxon, UK: Routledge; 2005: pp. 537-50

2. Vilar L, Araújo D, Davids K, Button C. The Role of Ecological Dynamics in Analysing Performance in Team Sports. Sports Med. 2012;42(1):1-10.

3. Martin E, Hine R. Oxford Dictionary of Biology. Oxford: Oxford University Press; 2008.

4. Bernstein N. The co-ordination and regulation of movements. London: Pergamon Press; 1967.

5. Turvey MT. Coordination. Am Psychol. 1990;45(8):938-53.

6. Schaal S. Arm and hand movement control. In: Arbib MA, editor. The handbook of brain theory and neural networks. 2nd ed. Cambridge, MA: The MIT Press; 2002: pp. 110-3

7. Fuchs A, Kelso JAS. A theoretical note on models of interlimb coordination. J Exp Psychol-Hum Percept Perform. 1994;20(5):1088-97.

8. Seifert L, Coeurjolly J-F, Hérault R, Wattebled L, Davids K. Temporal dynamics of inter-limb coordination in ice climbing revealed through change-point analysis of the geodesic mean of circular data. J Appl Statist. 2013;40(11):2317–31.

9. Kelso JAS. Dynamic Patterns: the self-organization of brain behavior. Cambridge, Massachusetts: The MIT Press; 1995.

10. Seifert L, Wattebled L, Herault R, Poizat G, Adé D, Gal-Petitfaux N, et al. Neurobiological Degeneracy and Affordance Perception Support Functional Intra-Individual Variability of Inter-Limb Coordination during Ice Climbing. PLoS ONE. 2014;9(2):e89865.

11. Schmidt RC, Carello C, Turvey MT. Phase Transitions and Critical Fluctuations in the Visual Coordination of Rhythmic Movements Between People. J Exp Psychol-Hum Percept Perform. 1990;16(2):227-47.

12. Schmidt RC, O'Brien BA, Sysko R. Self-Organization of Between-Persons Cooperative Tasks and Possible Applications to Sport. Int J Sport Psychol. 1999;30(4):558-79.

13. Stevens PS. Patterns in Nature. Westminster, UK: Penguin Books; 1976.

14. Varlet M, Richardson MJ. What Would Be Usain Bolt’s 100-Meter Sprint World Record Without Tyson Gay? Unintentional Interpersonal Synchronization Between the Two Sprinters. J Exp Psychol-Hum Percept Perform. 2015;41(1):36-41.

15. McGarry T, Franks I. In search of invariant athletic behaviour in competitive sport systems: An example from championship squash match-play. J Sports Sci. 1996;14(5):445-56.

16. Gréhaigne J-F, Bouthier D, David B. Dynamic-system analysis of opponent relationships in collective actions in soccer. J Sport Sci. 1997;15(2):137-49.

17. Bourbousson J, Séve C, McGarry T. Space-time coordination dynamics in basketball: Part 1. Intra- and inter-couplings among player dyads. J Sports Sci. 2010;28(3):339-47.

18. McGarry T, Anderson DI, Wallace SA, Hughes MD, Franks IM. Sport competition as a dynamical self-organizing system. J Sports Sci. 2002;20(10):771-81.

19. McGarry T. Soccer as a Dynamical System: Some Theoretical Considerations. In: Reilly T, Cabri J, Araújo D, editors. Science and Football V: The Proceedings of the Fifth World Congress on Science and Football. Oxon, UK: Routledge; 2005: pp. 551-60

20. Glazier PS. Game, Set and Match? Substantive Issues and Future Directions in Performance Analysis. Sports Med. 2010;40(8):625-34.

21. Duarte R, Araújo D, Correia V, Davids K. Sports Teams as Superorganisms. Sports Med. 2012;42(8):633-42.

22. Kelso JAS, Schöner G. Self-organization of coordinative movement patterns. Hum Movement Sci. 1988;7(1):27-46.

23. Haken H. Synergetics: An Introduction. Berlin: Springer; 1977.

24. McGarry T. Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. Int J Perform Anal Sport. 2009;9(1):128-40.

25. Passos P, Davids K. Learning design to facilitate interactive behaviours in Team Sports. Rev Int Cienc Deporte. 2015;11(39):18-32.

26. Orth D, Davids K, Araújo D, Renshaw I, Passos P. Effects of a defender on run-up velocity and ball speed when crossing a football. Eur J Sport Sci. 2014;14(Sup.1):S316-S23.

27. Headrick J, Davids K, Renshaw I, Araújo D, Passos P, Fernandes O. Proximity-to-goal as a constraint on patterns of behaviour in attacker-defender dyads in team games. J Sports Sci. 2012;30(3):247-53.

28. Duarte R, Araújo D, Davids K, Travassos B, Gazimba V, Sampaio J. Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes. J Sports Sci. 2012;30(9):871-7.

29. Passos P, Milho J, Fonseca S, Borges J, Araújo D, Davids K. Interpersonal Distance Regulates Functional Grouping Tendencies of Agents in Team Sports. J Mot Behav. 2011;43(2):155-63.

30. Duarte R, Araújo D, Freire L, Folgado H, Fernandes O, Davids K. Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. Hum Mov Sci. 2012;31(6):1639-51.

31. Duarte R, Araújo D, Fernandes O, Fonseca C, Correia V, Gazimba V, et al. Capturing complex human behaviors in representative sports contexts with a single camera. Medicina (Kaunas). 2010;46(6):408-14.

32. Frencken W, Lemmink K, Delleman N, Visscher C. Oscillations of centroid position and surface area of soccer teams in small-sided games. Eur J Sport Sci. 2011;11(4):215-23.

33. Frencken W, Lemmink K, Delleman NJ. Soccer-specific accuracy and validity of the local position measurement (LPM) system. J Sci Med Sport. 2010;13(6):641-5.

34. Bartlett R, Button C, Robins M, Dutt-Mazumder A, Kennedy G. Analysing Team Coordination Patterns from Player Movement Trajectories in Soccer: Methodological Considerations. Int J Perform Anal Sport. 2012;12(2):398-424.

35. Frencken W, de Poel H, Visscher C, Lemmink K. Variability of inter-team distances associated with match events in elite-standard soccer. J Sports Sci. 2012;30(12):1207-13.

36. Vilar L, Araújo D, Davids K, Bar-Yam Y. Science of winning soccer: emergent pattern-forming dynamics in association football. J Syst Sci Complex. 2013;26(1):73-84.

37. Gréhaigne JF, Mahut B, Fernandez A. Qualitative observation tools to analyse soccer. Int J Perform Anal Sport. 2001;1(1):52-61.

38. Shannon CE. A Mathematical Theory of Communication. Bell Syst Tech J. 1948;27(1):379-423, 623-56.

39. Carling C, Williams AM, Reilly T. Handbook of Soccer Match Analysis. New York: Routledge; 2005.

40. Pinder RA, Davids K, Renshaw I, Araújo D. Representative Learning Design and Functionality of Research and Practice in Sport. J Sport Exerc Psychol. 2011;33(1):146-55.

41. Araújo D, Davids K, Passos P. Ecological Validity, Representative Design, and Correspondence Between Experimental Task Constraints and Behavioral Setting: Comment on Rogers, Kadar, and Costall (2005). 2007;19(1):69-78.

42. Travassos B, Duarte R, Vilar L, Davids K, Araújo D. Practice task design in team sports: Representativeness enhanced by increasing opportunities for action. J Sports Sci. 2012;30(13):1447-54.

PAPER 2

Title: Design and reliability of a computational tool to analyze inter-team coordination patterns in soccer from video footage

Rodrigo Santos, Alexandre Brandão, Lucas Mantovani, Matheus Berger, Ricardo Duarte, Luís Vilar, Israel Teoldo

Abstract: Since computers have become an integral part of research and practice in sports performance analysis, automatic and semi-automatic tracking systems have been designed with the aim of reconstructing players' paths in team sports, and more particularly in soccer. Such devices include technologies such as global positioning (GPS), radio-based and video-based systems. However, these tools are often not user-friendly and frequently represent an expensive choice to track soccer players. So, the aim of this study is to present a novel computational tool to analyze inter-team coordination patterns in soccer from video footage. The instrument comprises low-cost and straightforward procedures in comparison with expensive and highly complex automatic tracking systems currently available. High reliability values indicate that this tool can be employed in a wide range of contexts within soccer and other team sports.

Keywords: Inter-team coordination; Soccer; MatLab.

1. Introduction

In sports, empirical investigation of players' and teams' actions alongside with data from video footage might provide athletes, coaches and sports scientists with valuable quantitative and qualitative evidence. Hence, once computers have become essential for research and practice in sports performance analysis (LESS, 1985), automatic and semi-automatic tracking systems have been designed with the aim of reconstructing players' paths in team sports, and more particularly in soccer (BARTLETT *et al.*, 2012). Such devices include technologies such as global positioning (GPS) and radio-based systems. In addition, video-based systems have also been conceived to track players' trajectories within the pitch through high definition cameras, which demand the identification of the players prior to the beginning of the tracking process. Nevertheless, these tools are often not user-friendly and frequently represent an expensive choice to track soccer players. However, straightforward and affordable instruments have been recently designed with the purpose of broadening the use of more qualitative data to investigate players' and teams' interactions.

Accordingly, technological tools that enable spatial tracking of players and teams might also contribute significantly to a clearer understanding of team sports behaviors through a dynamic approach (MCGARRY, 2009). In this sense, dynamic systems theory comprises numerous characteristics that are relevant for the investigation of interaction processes in sports (DAVIDS; ARAÚJO; SHUTTLEWORTH, 2005). Thus, the analysis of team sports (e.g. soccer) through the dynamic systems approach has attempted to emphasize how coordination among players/teams and the environment emerges (VILAR *et al.*, 2012). The study of interpersonal coordination patterns in soccer has currently become an emergent research topic. A recent investigation identified the importance of evaluating the number of players from each team in the different sub-areas of play as a means to capture inter-team coordination tendencies, so as to examine how instability emerges from teams' numerical advantage (VILAR *et al.*, 2013).

Therefore, once the data from the aforementioned investigation, as well as from most of the studies that examined interpersonal coordination patterns in team sports such as soccer, were obtained through automatic tracking methods, there is a need to develop practical, straightforward and accessible (i.e. low-cost) tools to quantify players' positional data from video footage, which may enhance the usability and generalization of these objective methods. So, the aim of this study is to present a novel computational tool to analyze inter-team coordination patterns in soccer from video footage.

2. Material and methods

The video footage used for this procedure is obtained through a common video camera positioned on the top of a stadium (or soccer field), behind one of the goals. Placing the camera in this position provides the operators with a bird's eye view of the entire field, including all players involved in match play. Video-recorded images of the matches are transferred to digital support and saved into ".avi" format.

From the location of all outfield players in each video frame, the effective play-space (EP-S) is calculated through the utilization of a MatLab® convex hull computation. The EP-S is defined as the polygonal area obtained through the imaginary line connecting all involved players located at the border of the play at a certain moment (GRÉHAIGNE, 1992; GRÉHAIGNE; MAHUT; FERNANDEZ, 2001). Therefore, in order to obtain the EP-S in each frame, 19 control points corresponding to some of the line markings on the pitch were employed to acquire accurate positional data, through the "maketform" function. The operator has to choose only four control points in each frame to determine players' positions in the field at a given moment. In order to carry out this procedure, the EP-S was divided into seven sub-areas (% of the total EP-S area), as seen in Fig. 1: Right Defensive (12.5%), Central Defensive (12.5%), Left Defensive (12.5%), Central Area (25%), Right Offensive (12.5%), Central Offensive (12.5%) and Left Offensive (12.5%). The analysis considers the allocation of players in this dynamically adaptive area of play, varying from frame to frame during the match (VILAR *et al.*, 2013).

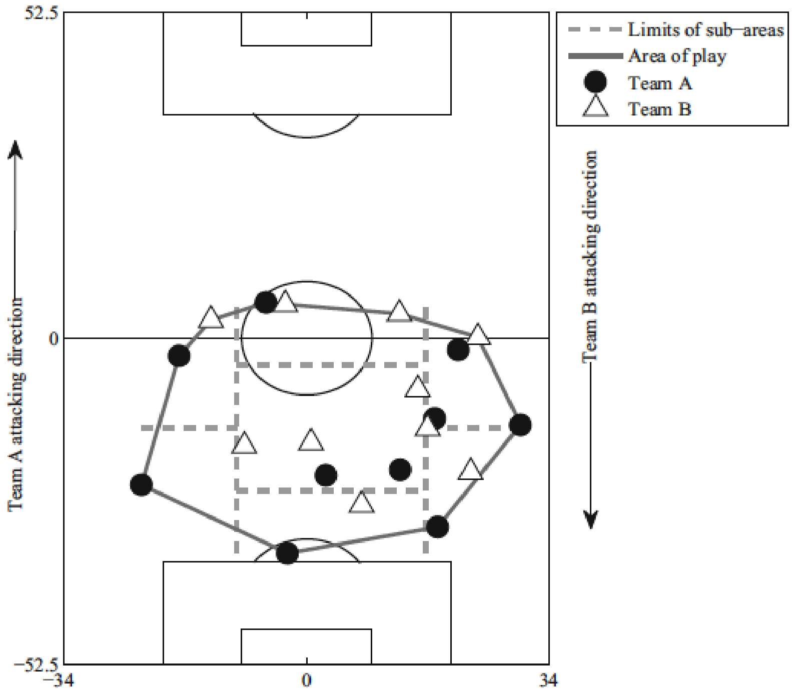

Fig. 1. Exemplar soccer pitch and location of all 20 outfield players within the sub-areas of the effective play-space (Reproduced from Vilar, Araújo, Davids and Bar-Yam, 2013).

In each frame the number of players from each team inside the different sub-areas of play is computed, and the script generates, through the creation of a spatial transformation structure ("maketform" function), a 2-D reconstruction of the players' pitch coordinates, the EP-S area and the location of the players within the sub-areas of play. In addition, the difference between the number of players from both teams, and the net team numerical advantage (disadvantage in case of negative values) is calculated (see complete flowchart in Fig. 2). The uncertainty of each team numerical advantage across sub-areas is also calculated through the utilization of Shannon's entropy, *H* (SHANNON, 1948):

$$H(x) = -\sum_{i} p(x_i)\log_2 p(x_i)$$

As outcome measures, this tool generates frequency and entropy histograms for each frame. All computations were performed with the utilization of MatLab® software.

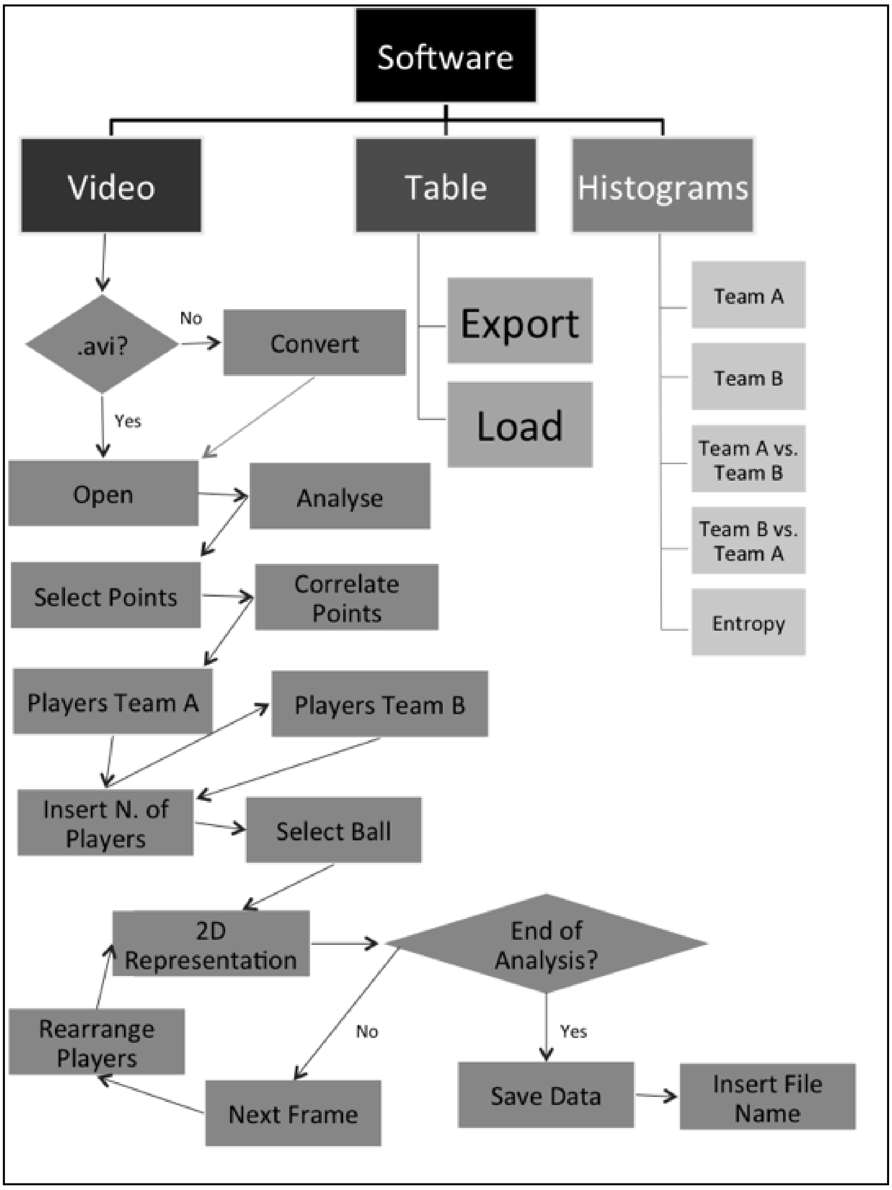

Fig. 2. Flowchart of the steps to analyze data and obtain information on numerical relations between teams through the analysis tool.

In order to obtain quality control of measurements, the digitizing operators undertook two weeks of a training program that consisted of the digitization of one or two (depending on the number of frames per sequence) goal-scoring plays per day. Cohen's kappa coefficients showed intra- and inter-operator reliability results that are classified as "almost perfect" (LANDIS; KOCH, 1977). Intra-operator reliability values ranged between 0.826 and 1 (Mean SE = 0.004), while inter-operator reliability displayed values ranging between 0.813 and 1 (Mean SE = 0.004).

3. Practical Implications

This paper presented a novel straightforward and low-cost computational tool (see exemplar screenshot in Fig. 3) to capture soccer players' relative positions and thus obtain information with respect to inter-team coordination patterns through relative numerical relations between teams within the sub-areas of play of the effective play-space. The high reliability values obtained indicate that this tool can be employed in a wide range of contexts within soccer (e.g. training and competition) and arguably other team sports.

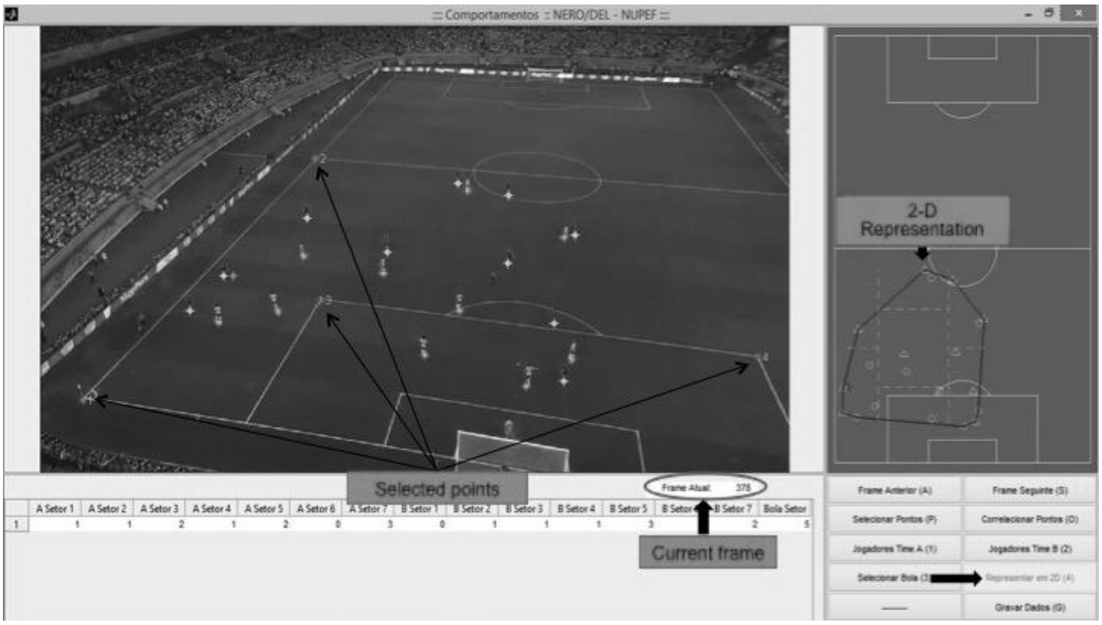

Fig. 3. Exemplar screenshot of the analysis tool with descriptions of some of its functions.

Identifying inter-team coordination patterns through numerical relations might allow detecting how defensive instability and offensive opportunity emerge from numerical advantage in key sub-areas of play. Also, considering that the ability to generate uncertainty in numbers in sub-areas closer to opponents' goal has been shown to be a potential indicator of successful performance (VILAR *et al.*, 2013) and that the level of environmental predictability might contribute to system disorders (DAVIDS; SMITH; MARTIN, 1991), the automatic calculation of Shannon's entropy (SHANNON, 1948) performed by our computational tool appears to be a valuable resource for researchers, match analysts and coaches, once it provides results immediately after the end of the analyzed frame.

Also, the usefulness of the tool presented here can be enhanced with respect to tracking procedures, since the inclusion of automatic video tracking routines will provide researchers and match analysts with more qualitative data in less time (KALAL; MIKOLAJCZYK; MATAS, 2010).

4. Conclusion

The present article presented the design and reliability procedures of a novel tool to analyze patterns of inter-team coordination in soccer. The instrument comprises low-cost and straightforward procedures, compared with expensive and highly complex automatic tracking systems currently available. In addition, high values of reliability measures confirmed the consistency of the analyses performed through this tool. Moreover, the improvement of the instrument through the incorporation of open-source automatic tracking routines might contribute to its timesaving features.

5. References

Bartlett, R., Button, C., Robins, M., Dutt-Mazumder, A., & Kennedy, G., 2012. Analysing Team Coordination Patterns from Player Movement Trajectories in Soccer: Methodological Considerations. Int. J. Perform. Anal. Sport, 12 (2), 398-424.

Davids, K., Araújo, D., & Shuttleworth, R. (2005). Applications of Dynamical Systems Theory to Football. In T. Reilly, J. Cabri & D. Araújo (Eds.), *Science and Football V: The Proceedings of the Fifth World Congress on Science and Football* (pp. 537-550). Oxon, UK: Routledge.

Davids, K., Smith, L., & Martin, R., 1991. Controlling system uncertainty in sport and work. Appl. Ergon., 22 (5), 312-315.

Gréhaigne, J.F., 1992. L'organisation du jeu en football [Game organization in soccer]. Joinville-le-Pont: Actio.

Gréhaigne, J.F., Mahut, B., & Fernandez, A., 2001. Qualitative observation tools to analyse soccer. Int. J. Perform. Anal. Sport, 1 (1), 52-61.

Kalal, Z., Mikolajczyk, K., & Matas, J., 2010. Tracking-Learning-Detection. IEEE Trans. Pattern Anal. Mach. Intell., 6 (1), 1-14.

Landis, R., & Koch, G.G., 1977. The Measurement of Observer Agreement for Categorical Data. Biometrics, 33 (1), 159-174.

Less, A., 1985. Computers in sport. Appl. Ergon., 16 (1), 3-10.

McGarry, T., 2009. Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. Int. J. Perform. Anal. Sport, 9 (1), 128-140.

Shannon, C.E., 1948. A Mathematical Theory of Communication. Bell Syst. Tech. J., 27 (1), 1-55.

Vilar, L., Araújo, D., Davids, K., & Bar-Yam, Y., 2013. Science of winning soccer: emergent pattern-forming dynamics in association football. J. Syst. Sci. Complex., 26 (1), 73-84.

Vilar, L., Araújo, D., Davids, K., & Button, C., 2012. The Role of Ecological Dynamics in Analysing Performance in Team Sports. Sports Med., 42 (1), 1-10.

PAPER 3

Title: Inter-team coordination tendencies of goal-scoring possessions in open play: an exploratory analysis of the 2014 FIFA® World Cup winner team

Rodrigo Santos, Ricardo Duarte, Luís Vilar, Ricardo Leão de Andrade, Júlio Garganta, Israel Teoldo

Abstract: Goal scoring is regarded as the ultimate indicator of offensive success in soccer. Hence, the investigations that analysed patterns that emerge from goal-scoring possessions frequently apply different approaches. The study aimed to examine the emergent inter-team coordination tendencies from goal-scoring possessions in open play of the 2014 FIFA® World Cup winner team, through the analysis of teams' numerical relations within the effective play-space. We hypothesized that in goal-scoring possessions Germany generate more numerical uncertainty in sub-areas of play closer to opponents' goal. We analysed 6457 frames (unit of analysis) from 11 video sequences of goal-scoring possessions. Teams' numerical relations within sub-areas of play were examined in each offensive sequence through Shannon's entropy. The uncertainty of numerical relationships between the teams across sub-areas was also calculated. Entropy measures indicated that the uncertainty of teams' numerical relations was higher within the German Central Offensive (opponents' Central Defensive) sub-area (1.86 bits) in comparison with the remaining sub-areas of play. These results suggest that goal-scoring possessions in open play apparently generate different patterns of inter-team coordination when compared to analyses of an entire match, which might not be able to reveal important patterns that emerge from key moments.

Keywords: Inter-team coordination; goal-scoring possessions; Germany.

1. Introduction

Goal scoring has been regarded as the ultimate indicator of offensive success in soccer (BATE, 1988; POLLARD; REEP, 1997). Therefore, it has drawn the attention of many sport scientists, since the analysis of actions that lead to goals and/or goal-scoring opportunities allows coaches and researchers to identify and employ the most effective playing methods in order to score and avoid conceding goals (HUGHES; FRANKS, 2005; REDWOOD-BROWN, 2008). Hence, the investigations that analysed patterns that emerge from goal-scoring possessions have frequently resorted to different approaches of analysis.

Arguably, one of the first studies that analysed goal-scoring patterns was conducted by (REEP; BENJAMIN, 1968) who reported that within the period between 1953 and 1967 nearly 80% of the goals scored in Premier League, World Cup and other miscellaneous matches were scored after sequences of 3 or less passes. However, the implications of such findings was questioned by (HUGHES; FRANKS, 2005) who indicated that the data displayed by (REEP; BENJAMIN, 1968) were not normalized and due to this fact, they suggested that results could have been misinterpreted. In another investigation, (YIANNAKOS; ARMATAS, 2006) verified that 44.1% of the goals in the UEFA® Euro 2004 were scored through an organized offensive move, while only 20.3% were scored through counterattacks. Also, the authors demonstrated that 63.4% of the goals in the referred tournament resulted from long passes and combination plays, while 17.1% resulted from individual actions. More recently, (TENGA *et al.*, 2010) indicated that counterattacks (13.4%) are more likely to lead to goals than elaborate attacks (8.8%). Likewise, long possessions (14.4%), mixed passing length (12.5%) and penetrative passes (25.4%) displayed higher probability of creating goals than short possessions (7.6%), long passes (2.6%) and non-penetrative passes (1.4%), respectively.

Nonetheless, although these investigations may provide relevant information about patterns that emerge from goal-scoring possessions, with respect to their methodological approach authors give little if any attention to the inter-team tendencies that underlie the actions observed in those sequences. Therefore, since it neglects the behaviours and reasons that make up performance profiles, the analysis methods employed by the investigations above are somewhat reductionist. Thus, research on team collective behaviour should focus on the interpersonal relationships between players during a match (ARAÚJO; DAVIDS; HRISTOVSKI, 2006; DUARTE; ARAÚJO; CORREIA*; et al.*, 2012). Such process of analysis allows to obtain more detailed data about the patterns underlying the configurations and functioning of play, since team structure should be contemplated as a whole and not only as the sum of the pieces that comprise it (GRÉHAIGNE; BOUTHIER; DAVID, 1997). Therefore, resorting to the study of interpersonal coordination with the purpose of capturing and describing patterns that emerge from the interactions between teammates and opponents is an approach that might certainly provide more relevant and useful information to researchers, coaches and players (MCGARRY, 2009; VILAR *et al.*, 2012).

In this regard, (BARTLETT *et al.*, 2012) analysed the coordination patterns between opposing teams in open play attacks from five matches in the group stage of the European Champions League, through the use of team centroids and other measures of dispersion. Findings from this study revealed no crossing of centroids of the two teams along the pitch for any of the goals scored in open play. The authors did not find substantial evidence that team centroids converge along the pitch during critical moments of the match, such as goals and shots on goal. Employing a similar approach, (MOURA *et al.*, 2012) analysed Brazilian teams' organization on the pitch for specific shot on goal and tackle situations, using measures of teams' coverage area and spread. Results displayed that while attacking, the teams exhibited a lower coverage area and spread when performing shots on goal compared to when they suffered tackles. However, team coverage area and spread were examined only within the exact frame in which the team performed a shot on goal, instead of considering the entire possession. Due to this limitation, there is not enough information about teams' collective patterns that led to goals and/or goal-scoring opportunities. Thus, since the structures and patterns of play are to be considered as a whole in a soccer match instead of being broken down into simple constituent elements (GRÉHAIGNE; BOUTHIER; DAVID, 1997), it is possible to assume that both aforementioned studies did not effectively reveal substantial information that could help understanding how interactions between teammates and opponents in the playing area resulted in successful outcomes.

Correspondingly, with respect to such interactions, (TEODORESCU, 1977) suggested that the coordinated work to generate numerical superiority in offensive and defensive sub-phases of play closer to the ball is vital to fulfil collective goals in team sports such as soccer. Hence, with the purpose of detecting and analysing such numerical relationships as well as their emerging patterns, (VILAR *et al.*, 2013) proposed a novel method to examine how teams occupy sub-areas of play. Through this approach, the authors analysed a soccer match based upon the hypothesis that local player numerical dominance is critical for defensive stability and offensive opportunity. The authors took into account a definition of the area of play, which was described as the area circumscribed by the location of the 20 outfield players. This concept was previously presented by other authors (MÉRAND, 1977; GRÉHAIGNE, 1992) as effective play-space (EP-S). The EP-S is defined as the polygonal area obtained through the imaginary line linking all involved players located at the periphery of play at a given instant.(GRÉHAIGNE; MAHUT; FERNANDEZ, 2001) The conception of EP-S implies that a structure of cooperation and opposition takes place between the elements of both teams in competitive opposition settings (GRÉHAIGNE; GODBOUT; ZERAI, 2011). Thus, the method proposed by (VILAR *et al.*, 2013) is a suitable approach for the investigation of inter-team coordination through the analysis of numerical relations, since it enables the examination of a given pattern of play through the notion of effective play-space (GRÉHAIGNE; GODBOUT, 2014). Consequently, we expect that through the utilization of this novel approach, the amount and quality of research addressing the analysis of emergent interpersonal coordination tendencies from goal-scoring possessions can substantially evolve.

Accordingly, the aim of this study is to examine the emergent inter-team coordination tendencies from goal-scoring possessions in open play of the 2014 FIFA® World Cup winner team, through the analysis of teams' numerical relations within the effective play-space. We hypothesize that in goal-scoring possessions this team generates more numerical uncertainty in sub-areas of play closer to opponents' goal.

2. Methods

We analysed 6457 frames (unit of analysis) from 11 video sequences of goal-scoring possessions in open play of the German National Soccer Team in the 2014 FIFA® World Cup in Brazil. Teams' numerical relations within sub-areas of play were examined in each offensive sequence that resulted in a goal scored by the German Team, so as to allow the investigation of emergent inter-team coordination tendencies. In order to classify the sub-areas of play, we resorted to the concept of effective play-space (EP-S), defined by (GRÉHAIGNE; MAHUT; FERNANDEZ, 2001) as the polygonal area obtained through the imaginary line linking all involved players located at the periphery of play at a given instant. The video footage used for analysis was obtained through publicly available broadcast images. Editing of video footage of goal-scoring possessions in open play was performed through the utilization of SportsCode Pro®, Version 10.3 (Sportstec, Warriewood, NSW, Australia).

From the location of all outfield players in each video frame, the effective play-space (EP-S) was calculated through the utilization of a MatLab® convex hull computation. For this, 19 control points corresponding to some of the line markings on the pitch were employed to obtain accurate positional data, through the "maketform" function. It is necessary to choose only four control points in each frame to determine players' positions in the field at a given moment. For this procedure, the EP-S was divided into seven sub-areas (% of the total EP-S area), as shown in Fig. 1: Right Defensive (12.5%), Central Defensive (12.5%), Left Defensive (12.5%), Central Area (25%), Right Offensive (12.5%), Central Offensive (12.5%) and Left Offensive (12.5%). The analysis considers the distribution of players in this dynamically adaptive area of play, changing from frame to frame during the match (VILAR *et al.*, 2013). In each frame the number of players from each team inside the different sub-areas of play is computed, and the script generates, through a spatial transformation, a 2-D reconstruction of the players' pitch coordinates, the EP-S area and the location of the players within the sub-areas. Also, the numerical difference between both teams in each sub-area is calculated.

The uncertainty of numerical relationships between the teams across sub-areas is also calculated through the utilization of Shannon's entropy, *H* (SHANNON, 1948). As outcome measures, this tool generates frequency and entropy (measured in bits) histograms for each video sequence. Friedman and Wilcoxon's matched-pairs signed-ranks tests were performed to verify differences in entropy values between sub-areas in each goal-scoring possession. Significance level was set to $p<0.05$. All computational and statistical procedures were performed through MatLab® 2012b and IBM® SPSS v.22.

3. Results

We start by describing the patterns of frequency distribution of the German team and their opponents. Next, we present the coordination between German and opposite players according to the numerical relationships established within the sub-areas of play. Ultimately, we analyse the uncertainty in numbers across the sub-areas of play.

Teams' frequency distribution (Fig. 1) within sub-areas of play displayed a tendency of the German team to have at least 2 players in the Central Defensive sub-area for 55.5% of the time. In the Right Defensive and Left Defensive sub-areas of play, the team usually allocated 1 player for 65.1% and 47.7% of the time, respectively, while in the Central Midfield sub-area, they allocated 2 players for 43.6% of the time. Regarding the offensive sub-areas, the German team often allocated 1 player within the Central Offensive (39.6% of the time), Right Offensive (47.1% of the time) and Left Offensive (39.9% of the time) sub-areas of play.

On the other hand, Fig. 2 shows that Germany's opponents usually had 2 players within their Central Defensive sub-area of play for 34.4% of the time and 1 player in the Right and Left Defensive sub-areas for 39.3% and 43.6% of the time, respectively, while in the Central Midfield sub-area, they often allocated 1 player for 32.4% of the time. Also, the opposing teams generally had no players within the Right and Left Offensive sub-areas of play (57.9% and 48.5% of the time, respectively) and usually allocated only 1 player in the Central Offensive sub-area of play (73.4% of the time).

Results demonstrated an emphasis of the German Team on defensive numerical stability, given that the most likely team numerical difference in the Central Defensive sub-area is +1. This tendency is evident for 52.1% of the analysed frames. Also, according to Fig. 3, it was possible to observe that the team generates numerical equality or superiority for 64.1% of the time in the Central Midfield, 77.6% in the Right Offensive and 68.1% in the Left Offensive sub-areas of play. On the other hand, such equality/superiority was not apparent within the Central Offensive sub-area, since the German team was not able to generate numerical equality or superiority in this sub-area for more than 23% of the time.

However, entropy measures (Fig. 4) indicated that the uncertainty of teams' numerical relations was higher within the German Central Offensive (opponents'

Central Defensive) sub-area (1.86 bits) in comparison with the remaining sub-areas of play. Central Midfield (1.80 bits) and Left Offensive (opponents' Right Defensive - 1.76 bits) sub-areas of play also displayed considerable entropy values.

Friedman test indicated significant statistical differences (Tab. 1) in entropy values between sub-areas of play (p=0.001). Wilcoxon's matched-pairs signed-ranks test revealed that Central Offensive sub-area of play (opponents' Central Defensive) displayed a significantly higher entropy value in comparison to Right Defensive (opponents' Left Offensive), Left Defensive (opponents' Right Offensive) and Right Offensive (opponents' Left Defensive) sub-areas of play (p=0.003; p=0.021 and p=0.008, respectively).

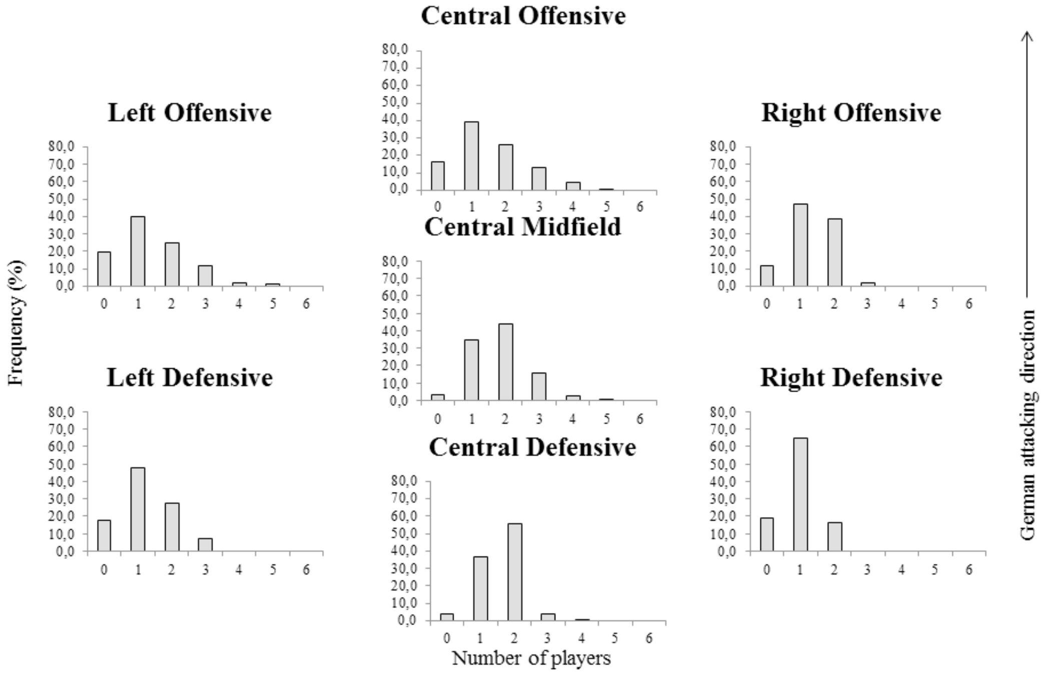

Fig. 1 Frequency histograms of the German team in their different sub-areas of play, in all goal-scoring possessions in open play.

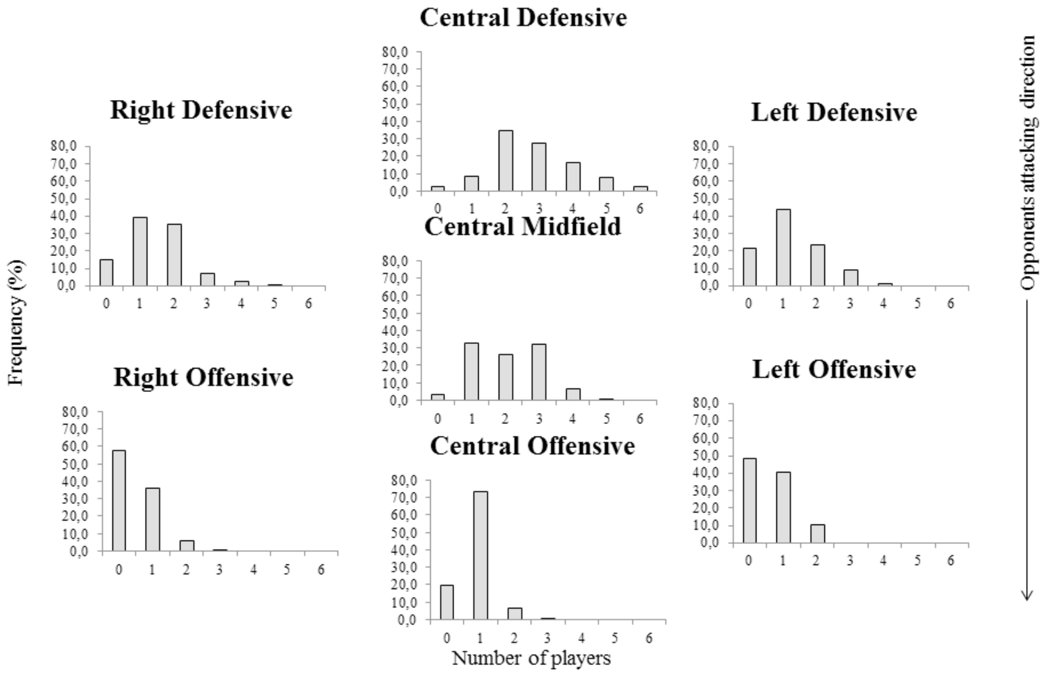

Fig. 2 Frequency histograms of Germany's opposing teams in their different sub-areas of play, in all goal-scoring possessions in open play.

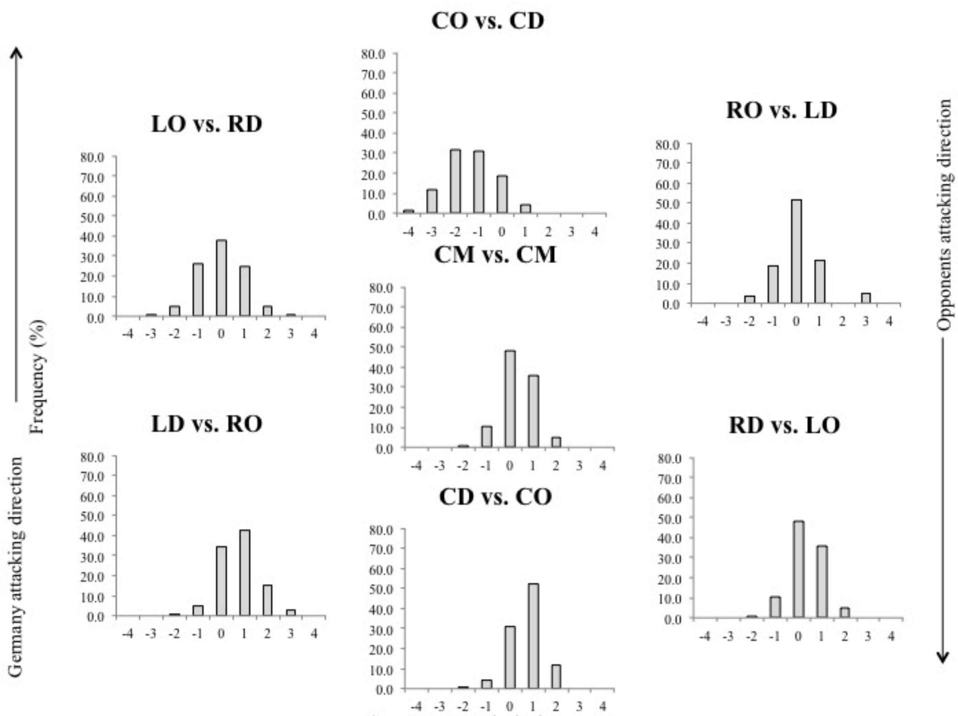

Fig. 3 Frequency histograms of Germany's numerical advantage (disadvantage for negative values).

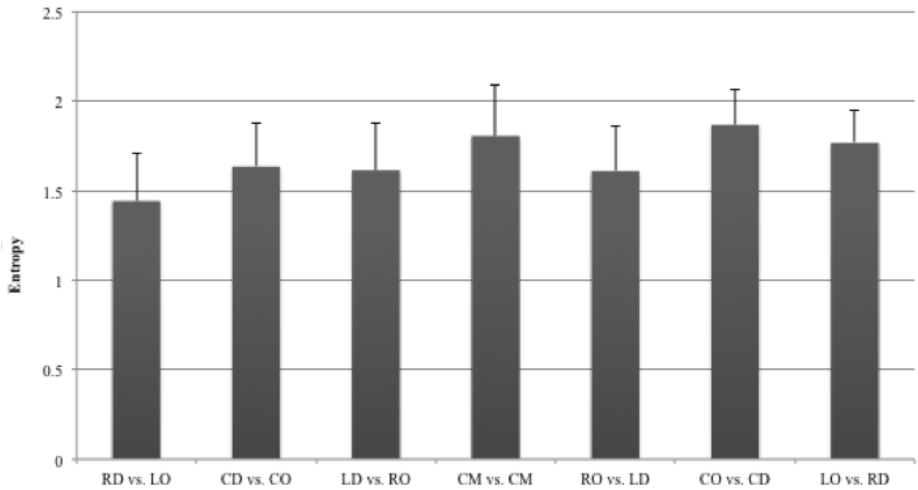

Fig. 4 Uncertainty of team numerical relations in each sub-area of play. The *x* axis displays the opposing sub-areas of play of Germany and their opponents: Germany's Right (RD) and Left (LD) Defensive correspond to opponents' Left (LO) and Right (RO) Offensive sub-areas of play (and vice-versa); Germany's Central Defensive (CD) corresponds to opponents' Central Offensive (CO) sub-area of play (and vice-versa).

Table 1
Values of significance of the Wilcoxon's matched-pairs signed-ranks test with respect to the comparison of entropy values across the different sub-areas of play (*p<0.05). Values are duplicated within rows and columns.

Sub-Area	RD vs. LO	CD vs. CO	LD vs. RO	CM vs. CM	RO vs. LD	CO vs. CD	LO vs. RD
RD vs. LO	-	**0.016***	0.059	**0.004***	0.062	**0.003***	**0.008***
CD vs. CO	**0.016***	-	0.859	**0.016***	0.859	0.050	0.110
LD vs. RO	0.059	0.859	-	**0.041***	0.929	**0.021***	**0.033***
CM vs. CM	**0.004***	**0.016***	**0.041***	-	0.155	0.328	0.790
RO vs. LD	0.062	0.859	0.929	0.155	-	**0.008***	0.050
CO vs. CD	**0.003***	0.050	**0.021***	0.328	**0.021***	-	0.110
LO vs. RD	**0.008***	0.110	**0.033***	0.790	0.050	0.110	-

4. Discussion

Frequency and uncertainty of numerical relations between the German National Soccer Team and their opponents were analysed to identify emergent inter-team coordination tendencies from goal-scoring possessions in open play during the 2014 FIFA® World Cup. More specifically, this study examined the frequency of Germany and opponents' players within each sub-area of play, as well as the variability of teams' numerical differences across sub-areas. Results indicated that the German team generates higher uncertainty in sub-areas of play closer to opponents' goal (CO and LO) in comparison to less risky sub-areas of play, despite having displayed numerical inferiority within these sub-areas for most of the time.

With respect to teams' frequency distribution across sub-areas of play, the present investigation revealed that the German team often allocated two players within the Central Defensive sub-area of play (55.5%), and one player within the Right and Left Defensive sub-areas of play (65.1% and 47.7%, respectively). In the study conducted by (VILAR *et al.*, 2013), the authors analysed a single match of the English Premiership and reported similar findings in relation to those within the present investigation. Such correspondence might indicate that, broadly speaking, top-level teams tend to comply with their respective formations either during the entire match or in key moments such as goal-scoring possessions.

On the other hand, in terms of numerical relations, the findings of the aforementioned study slightly differ from those presented within this paper. In their investigation, (VILAR *et al.*, 2013) reported a tendency of the winner team to be in numerical equality in both Right and Left Defensive sub-areas of play, while our results displayed that during goal-scoring possessions, the German team have the same number of players in relation to their opponents only within the Right Defensive sub-area of play (48.3%). Also, although in the first study authors found numerical equality in only one of the offensive flanks (Right Offensive sub-area), our results displayed that the German team were able to generate 1vs.1 situations, since they exhibited numerical equality for most of the time in both Right and Left Offensive sub-areas of play. Regarding the Central Offensive sub-area of play, both studies have found similar patterns, whereas Germany displayed numerical disadvantage within this sub-area for most of the time. From these findings it is possible to infer that there is a pattern of space management by the players in defence, since (WALLACE; NORTON, 2014), in a study that investigated elements of game structure in World Cup finals over the period between 1966 and 2010, reported that player density increased over such period. According to the authors, player density is an indicator of congestion that plays a crucial role in effective and ineffective playing patterns, whereas decreased player density provides attacking players with more time and space, thus increasing opportunities to score. Instead, defenders will try to increase density near the attacking players, with the aim of reduce the space and anticipate their subsequent actions.

However, with respect to the entropy measures across sub-areas of play, findings of the present investigation indicated that Germany was able to generate higher uncertainty within the Central Offensive sub-area of play, which is the area of most risk for the opponents' goal. Therefore, these results suggest that goal-scoring possessions in open play apparently generate different patterns of inter-team coordination when compared to analyses of an entire match, which might not be able to reveal important patterns that emerge from key moments. In this regard, results reported by (TENGA *et al.*, 2010), who examined the effect of playing tactics on goal scoring by analysing interactions between opponents in the Norwegian professional league, might somewhat support our findings, since the authors revealed that 94% of the goals were scored against an imbalanced defence, thus suggesting that goals often emerge from defensive instability (or, from an analogous perspective, uncertainty). Likewise, by examining inter-team distances in a UEFA® Champions League quarter-final match, (FRENCKEN *et al.*, 2012) hypothesised that a period of high variability would precede critical match events, such as goals and goal-scoring opportunities. Nevertheless, it should be taken into account that the study design and the analysis method employed, as well as some of the variables examined in the aforementioned investigations were different from those utilized by the authors within the present article. Finally, these findings reveal trends that suggest the manner through which players deal with problems related to information within the match, since that, according to (GRÉHAIGNE; BOUTHIER; DAVID, 1997), they have to manage the generation of certainty (for teammates) and uncertainty (to opponents).

5. Conclusion

This study on match performance analysis has investigated the patterns of inter-team coordination that emerge from goal-scoring possessions in open play of the 2014 FIFA® World Cup winner team, through the study of numerical relations within the effective play-space (EP-S). Since goal scoring is the most important outcome variable in soccer, investigating the patterns that lead to goals is paramount for match performance analysts and sport scientists. Furthermore, the detection of goal-scoring patterns that go beyond the description of discrete actions would obviously contribute to enhance the quality of training sessions and players' competitive performance. In this respect, generating numerical uncertainty within sub-areas of play closer to opponent's goal is possibly a potential indicator of success in goal-scoring possessions. Researchers should conduct further investigations to confirm this trend and increase the likelihood of generalizability of such findings.

Practical Implications

- Coaches should focus their training sessions on the development of players' ability of managing numerical certainty and uncertainty.
- Small-sided games in which players are required to deal with numerical inferiority/superiority are highly recommended.

Acknowledgment

This study was funded by the State Department of Tourism and Sports of Minas Gerais (SETES-MG) through the State Act of Incentive to Sports, by FAPEMIG, CAPES, CNPQ, FUNARBE, the Dean's Office for Graduate and Research Studies and the Centre of Life and Health Sciences from the Universidade Federal de Viçosa, Brazil.

6. References

1. Pollard R., Reep C., Measuring the effectiveness of playing strategies at soccer. *The Statistician*, 1997, 46 (4), 541-550.

2. Bate R. Football chance: tactics and strategy. In: Reilly T., Lees A., Davids K., Murphy W.J. editors. Science and Football: Proceedings of first World Congress of Science and Football. E. & F. N. Spon Ltd, London, 1988, 293-301.

3. Hughes M., Franks I., Analysis of passing sequences, shots and goals in soccer. *J Sports Sci*, 2005, 23 (5), 509–514.

4. Redwood-Brown A., Passing patterns before and after goal scoring in FA Premier League Soccer. *Int J Perform Anal Sport,* 2008, 8 (3), 172-182.

5. Reep C., Benjamin B., Skill and Chance in Association Football. *J R Stat Soc*, 1968, 131 (4), 581-585.

6. Yiannakos A., Armatas V., Evaluation of the goal scoring patterns in European Championship in Portugal 2004. *Int J Perform Anal Sport*, 2006, 6 (1), 178-188.

7. Tenga A., Holme I., Ronglan L.T., Bahr R., Effect of playing tactics on goal scoring in Norwegian professional soccer. *J Sports Sci*, 2010, 28 (3), 237-244.

8. Duarte R., Araújo D., Correia V., Davids K., Sports Teams as Superorganisms. *Sports Med*, 2012, 42 (8), 633-642.

9. Araújo D., Davids K., Hristovski R., The ecological dynamics of decision making in sport. *Psychol Sport Exerc*, 2006, 7 (6), 653-676, doi: 10.1016/j.psychsport.2006.07.002.

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

11. McGarry T., Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. *Int J Perform Anal Sport*, 2009, 9 (1), 128-140.

12. Vilar L., Araújo D., Davids K., Button C., The Role of Ecological Dynamics in Analysing Performance in Team Sports. *Sports Med*, 2012, 42 (1), 1-10.

13. Bartlett R., Button C., Robins M., Dutt-Mazumder A., Kennedy G., Analysing Team Coordination Patterns from Player Movement Trajectories in Soccer: Methodological Considerations. *Int J Perform Anal Sport*, 2012, 12 (2), 398-424.

14. Moura F.A., Martins L.E.B., Anido R.O., Barros R.M.L., Cunha S.A., Quantitative analysis of Brazilian football players' organisation on the pitch. *Sports Biomech*, 2012, 11 (1), 85-96.

15. Teodorescu L. Théorie et méthodologie des jeux sportifs. Paris: Les Editeurs Français Réunis, 1977.

16. Vilar L., Araújo D., Davids K., Bar-Yam Y., Science of winning soccer: emergent pattern-forming dynamics in association football. *J Syst Sci Complex*, 2013, 26 (1), 73-84.

17. Mérand R. L'éducateur face à la haute performance olympique. Paris, France: Sport et Plein Air, 1977.

18. Gréhaigne J.F. L'organisation du jeu en football [Game organization in soccer]. Joinville-le-Pont: Actio, 1992.

19. Gréhaigne J.F., Mahut B., Fernandez A., Qualitative observation tools to analyse soccer. *Int J Perform Anal Sport*, 2001, 1 (1), 52-61.

20. Gréhaigne J.-F., Godbout P., Zerai Z., How the "rapport de forces" evolves in a soccer match: the dynamics of collective decisions in a complex system. *Rev Psicol Deporte*, 2011, 20 (2), 747-765.

21. Gréhaigne J.-F., Godbout P., Dynamic Systems Theory and Team Sport Coaching. *Quest*, 2014, 66 (1), 96-116.

22. Shannon C.E., A Mathematical Theory of Communication. *Bell Syst Tech J*, 1948, 27 (1), 1-55.

23. Wallace J.L., Norton K.I., Evolution of World Cup soccer final games 1966-2010: Game structure, speed and play patterns. *J Sci Med Sport*, 2014, 17 (2), 223-228, doi: 10.1016/j.jsams.2013.03.016.

24. Frencken W., de Poel H., Visscher C., Lemmink K., Variability of inter-team distances associated with match events in elite-standard soccer. *J Sports Sci*, 2012, 30 (12), 1207-1213, doi: 10.1080/02640414.2012.703783.

GENERAL DISCUSSION AND CONCLUSION

This study showed that the information acquired by means of the investigation of inter-team coordination patterns, through the analysis of numerical relations, might allow coaches and match analysts to observe defenders' proficiency when dealing with attackers' efforts to progress through the pitch and create scoring opportunities. In addition, representative task design in experimental and training settings should rely upon the behaviours and performances observed in actual match contexts. Therefore, the utilization of sub-phases of the game (1vs.1, 3vs.3, etc.) in research and training should take into account that in order to provide players with accurately simulated gathering and utilization of information experimental and training tasks demand the conservation of action fidelity, so as to stimulate representative (in relation to real match situations) and accurate decisions during the game (TRAVASSOS *et al.*, 2012).

In relation to the utilization of numerical relations to examine teams' coordination, researchers should attempt to put this new method to use with increased sample sizes (higher number of matches) and also to investigate whether the patterns of coordination that emerge from key events (e.g. creation of goal-scoring opportunities) are related to those observed during an entire match. Also, match analysts and/or coaches might use this information to study opponents' instabilities and to increase the number of goal-scoring opportunities of their own teams, by exploring the level of uncertainty of numerical relations within the EP-S.

The second paper indicated that the identification of inter-team coordination patterns through numerical relations might allow detecting how defensive instability and offensive opportunity emerge from numerical advantage in key sub-areas of play. In addition, considering that the ability to generate uncertainty in numbers in sub-areas closer to opponents' goal has been shown to be a potential indicator of successful performance (VILAR *et al.*, 2013) and that the level of environmental predictability might contribute to system disorders (DAVIDS; SMITH; MARTIN, 1991), the automatic calculation of Shannon's entropy (SHANNON, 1948) performed by the computational tool presented in this study appears to be a valuable resource for the study of once it provides results immediately after the end of the analyzed frame. Also, the high intra- and inter-operator reliability values and the reduced standard error reported in this paper, suggests that researchers and match analysts might benefit from this analysis tool to provide coaches with more qualitative information with respect to how patterns of play emerge from players' and teams' interactions.

Finally, the exploratory paper on match performance analysis aimed to investigate the patterns of inter-team coordination that emerged from goal-scoring possessions in open play of the 2014 FIFA® World Cup winner team. Specifically, we quantified the numerical relations within the effective play-space (EP-S). Results indicated the German team generates higher uncertainty in sub-areas of play closer to opponents' goal (CO and LO) in comparison to less risky sub-areas of play, despite having displayed numerical inferiority within these sub-areas for most of the time. The study of Barreira et al. (2015) reported that relative numerical inferiority in the centre of play increased between 2002 and 2010, and that the actions with numerical equality and favourable conditions to resume offensive sequences in the lack of pressure decreased significantly within the same period. Therefore, the findings of the aforementioned research allow us to infer that the ability to generate numerical superiority in key areas of the pitch might be an essential feature for optimal collective performance in soccer. Thus, the competence to generate numerical uncertainty in vital areas may be a possible explanation (with respect to the tactical aspects of the game) for the successful results of the German National Team in the 2014 FIFA® World Cup. Nonetheless, the tendencies displayed by our results might be an important step to uncover the manner through which players deal with problems related to information within a match, since that according to Gréhaigne, Bouthier and David (1997), they have to manage certainty, to teammates, and uncertainty, to opponents. Furthermore, the detection of goal-scoring patterns that go beyond the analysis of discrete actions could positively contribute to enhance the quality of training sessions and players' competitive performance. In this respect, generating numerical uncertainty within sub-areas of play closer to opponent's goal is possibly a potential indicator of success in goal-scoring possessions. Also, coaches might benefit from these findings by developing training drills in which players have to deal with numerical superiority/inferiority, in order to manage uncertainty optimally (SILVA *et al.*, 2014). Future research should conduct further investigations to confirm this trend and increase the likelihood of generalizability of these findings.

By and large, this study provided a solid theoretical background, a reliable analysis tool and empirical evidence to support the utilization of interpersonal coordination through the analysis of inter-team relative numerical relations, as a means to identify emergent patterns of play in goal-scoring possessions. Also, since *player-player* and *team-team* coordination tendencies are likely to adapt to the performance constraints within the game, the manipulation of numerical relations in small-sided and conditioned games (SSCGs) during training sessions appears to be a feasible means to generate shared affordances, so as to support the emergence of efficient coordinated group and collective behaviours. Last, this study confirm the implications of recent empirical findings, which support the notion that inter-team coordination might be described as an emergent process, and therefore ruled by laws of dynamical systems. Therefore, analysing teams and players' behaviour in the light of the dynamical systems theory is a suitable approach to unfold and explain decision-making behaviour at the individual and collective level in soccer.

GENERAL REFERENCES

ARAÚJO, D.; DAVIDS, K.; HRISTOVSKI, R. The ecological dynamics of decision making in sport. **Psychology of Sport and Exercise**, v.7, n.6, p.653-676. 2006.

ARAÚJO, D.; DAVIDS, K.; PASSOS, P. Ecological Validity, Representative Design, and Correspondence Between Experimental Task Constraints and Behavioral Setting: Comment on Rogers, Kadar, and Costall (2005). **Ecological Psychology**, v.19, n.1, p.69-78. 2007.

ATLAN, H. **Entre le cristal et la fumée**. Paris: Seuil. 1986. 285 p.

BARREIRA, D.; GARGANTA, J.; CASTELLANO, J.; MACHADO, J.; ANGUERA, M. T. How elite-level soccer dynamics has evolved over the last three decades? Input from generalizability theory. **Cuadernos de Psicología del Deporte**, v.15, n.1, p.51-62. 2015.

BARTLETT, R.; BUTTON, C.; ROBINS, M.; DUTT-MAZUMDER, A.; KENNEDY, G. Analysing Team Coordination Patterns from Player Movement Trajectories in Soccer: Methodological Considerations. **International Journal of Perfomance Analysis in Sport**, v.12, n.2, p.398-424. 2012.

BATE, R. Football chance: tactics and strategy. In: T. Reilly, A. Lees, K. Davids e W. J. Murphy (Ed.). **Science and Football: Proceedings of first World Congress of Science and Football**. London: E. & F. N. Spon Ltd, 1988, p.293-301.

BERNSTEIN, N. **The co-ordination and regulation of movements**. London: Pergamon Press. 1967. 196 p.

BORRIE, A.; JONES, K. It's not what you do it's the way that you do it: is frequency of occurrence and adequate index of performance in observational analysis? **Journal of Sports Sciences**, v.16, n.1, p.14. 1998.

BORRIE, A.; JONSSON, G. K.; MANGNUSSON, M. S. Temporal pattern analysis and its applicability in sport: an explanation and exemplar data. **Journal of Sports Sciences**, v.20, n.10, p.845-852. 2002.

BOURBOUSSON, J.; SÉVE, C.; MCGARRY, T. Space-time coordination dynamics in basketball: Part 1. Intra- and inter-couplings among player dyads. **Journal of Sports Sciences**, v.28, n.3, p.339-347. 2010.

CARLING, C.; WILLIAMS, A. M.; REILLY, T. **Handbook of Soccer Match Analysis**. New York: Routledge. 2005.

CLEMENTE, F. M.; COUCEIRO, M. S.; MARTINS, F. M. L.; DIAS, G.; MENDES, R. Interpersonal Dynamics: 1v1 Sub-Phase at Sub-18 Football Players. **Journal of Human Kinetics**, v.36, p.181-191. 2013.

DAVIDS, K.; ARAÚJO, D.; SHUTTLEWORTH, R. Applications of Dynamical Systems Theory to Football. In: T. Reilly, J. Cabri e D. Araújo (Ed.). **Science and Football V: The Proceedings of the Fifth World Congress on Science and Football**. Oxon, UK: Routledge, 2005, p.537-550.

DAVIDS, K.; SMITH, L.; MARTIN, R. Controlling system uncertainty in sport and work. **Applied Ergonomics**, v.22, n.5, p.312-315. 1991.

DRUST, B.; ATKINSON, G.; REILLY, T. Future Perspectives in the Evaluation of the Physiological Demands of Soccer. **Sports Medicine**, v.37, n.9, p.783-805. 2007.

DUARTE, R.; ARAÚJO, D.; CORREIA, V.; DAVIDS, K. Sports Teams as Superorganisms. **Sports Medicine**, v.42, n.8, p.633-642. 2012.

DUARTE, R.; ARAÚJO, D.; CORREIA, V.; DAVIDS, K.; MARQUES, P.; RICHARDSON, M. J. Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. **Human Movement Science**, v.32, n.4, p.555-566. 2013.

DUARTE, R.; ARAÚJO, D.; DAVIDS, K.; TRAVASSOS, B.; GAZIMBA, V.; SAMPAIO, J. Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes. **Journal of Sports Sciences**, v.30, n.9, p.871-877. 2012a.

DUARTE, R.; ARAÚJO, D.; DAVIDS, K.; TRAVASSOS, B.; GAZIMBA, V.; SAMPAIO, J. Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes in youth soccer. **Journal of Sports Sciences**, v.30, n.9, p.871-877. 2012b.

DUARTE, R.; ARAÚJO, D.; FERNANDES, O.; FONSECA, C.; CORREIA, V.; GAZIMBA, V.; TRAVASSOS, B.; ESTEVES, P.; VILAR, L.; LOPES, J. Capturing complex human behaviors in representative sports contexts with a single camera. **Medicina (Kaunas)**, v.46, n.6, p.408-414. 2010.

DUARTE, R.; ARAÚJO, D.; FREIRE, L.; FOLGADO, H.; FERNANDES, O.; DAVIDS, K. Intra- and inter-group coordination patterns reveal collective behaviors of football players near the scoring zone. **Human Movement Science**, v.31, n.6, p.1639-1651. 2012.

FRENCKEN, W.; DE POEL, H.; VISSCHER, C.; LEMMINK, K. Variability of inter-team distances associated with match events in elite-standard soccer. **Journal of Sports Sciences**, v.30, n.12, p.1207-1213. 2012.

FRENCKEN, W.; LEMMINK, K.; DELLEMAN, N.; VISSCHER, C. Oscillations of centroid position and surface area of soccer teams in small-sided games. **European Journal of Sport Science**, v.11, n.4, p.215-223. 2011.

FRENCKEN, W.; LEMMINK, K.; DELLEMAN, N. J. Soccer-specific accuracy and validity of the local position measurement (LPM) system. **Journal of Science and Medicine in Sport**, v.13, n.6, p.641-645. 2010.

FUCHS, A.; KELSO, J. A. S. A theoretical note on models of interlimb coordination. **Journal of Experimental Psychology: Human Perception and Performance**, v.20, n.5, p.1088-1097. 1994.

GARGANTA, J. Trends of tactical performance analysis in team sports: bridging the gap between research, training and competition. **Revista Portuguesa de Ciências do Desporto**, v.9, n.1, p.81-89. 2009.

GLAZIER, P. S. Game, Set and Match? Substantive Issues and Future Directions in Performance Analysis. **Sports Medicine**, v.40, n.8, p.625-634. 2010.

GRÉHAIGNE, J.-F.; BOUTHIER, D.; DAVID, B. Dynamic-system analysis of opponent relationships in collective actions in soccer. **Journal of Sports Sciences**, v.15, n.2, p.137-149. 1997.

GRÉHAIGNE, J.-F.; GODBOUT, P. Dynamic Systems Theory and Team Sport Coaching. **Quest**, v.66, n.1, p.96-116. 2014.

GRÉHAIGNE, J.-F.; GODBOUT, P.; ZERAI, Z. How the "rapport de forces" evolves in a soccer match: the dynamics of collective decisions in a complex system. **Revista de Psicología del Deporte**, v.20, n.2, p.747-765. 2011.

GRÉHAIGNE, J. F. **L'organisation du jeu en football**. Joinville-le-Pont: Actio. 1992. 194 p.

GRÉHAIGNE, J. F.; MAHUT, B.; FERNANDEZ, A. Qualitative observation tools to analyse soccer. **International Journal of Perfomance Analysis in Sport**, v.1, n.1, p.52-61. 2001.

HAKEN, H. **Synergetics: An Introduction**. Berlin: Springer. 1977. 408 p.

HEADRICK, J.; DAVIDS, K.; RENSHAW, I.; ARAÚJO, D.; PASSOS, P.; FERNANDES, O. Proximity-to-goal as a constraint on patterns of behaviour in attacker-defender dyads in team games. **Journal of Sports Sciences**, v.30, n.3, p.247-253. 2012.

HUGHES, M.; FRANKS, I. Analysis of passing sequences, shots and goals in soccer. **Journal of Sports Sciences**, v.23, n.5, maio, p.509–514. 2005.

HUGHES, M.; FRANKS, I. M. **Notational Analysis of Sport**. New York: Routledge. 2004. 304 p.

KALAL, Z.; MIKOLAJCZYK, K.; MATAS, J. Tracking-Learning-Detection. **IEEE Transactions on Pattern Analysis and Machine Intelligence**, v.6, n.1, p.1-14. 2010.

KELSO, J. A. S. **Dynamic Patterns: the self-organization of brain behavior**. Cambridge, Massachusetts: The MIT Press. 1995. 334 p.

KELSO, J. A. S.; SCHÖNER, G. Self-organization of coordinative movement patterns. **Human Movement Science**, v.7, n.1, p.27-46. 1988.

LANDIS, R.; KOCH, G. G. The Measurement of Observer Agreement for Categorical Data. **Biometrics**, v.33, n.1, p.159-174. 1977.

LESS, A. Computers in sport. **Applied Ergonomics**, v.16, n.1, p.3-10. 1985.

MACKENZIE, R.; CUSHION, C. Performance analysis in football: A critical review and implications for future research. **Journal of Sports Sciences**, v.31, n.6, p.639-676. 2013.

MARTIN, E.; HINE, R. **Oxford Dictionary of Biology**. Oxford: Oxford University Press. 2008. 736 p.

MCGARRY, T. Soccer as a Dynamical System: Some Theoretical Considerations. In: T. Reilly, J. Cabri e D. Araújo (Ed.). **Science and Football V: The Proceedings**

of the Fifth World Congress on Science and Football. Oxon, UK: Routledge, 2005, p.551-560.

MCGARRY, T. Applied and theoretical perspectives of performance analysis in sport: Scientific issues and challenges. **International Journal of Perfomance Analysis in Sport**, v.9, n.1, p.128-140. 2009.

MCGARRY, T.; ANDERSON, D. I.; WALLACE, S. A.; HUGHES, M. D.; FRANKS, I. M. Sport competition as a dynamical self-organizing system. **Journal of Sports Sciences**, v.20, n.10, p.771-781. 2002.

MCGARRY, T.; FRANKS, I. In search of invariant athletic behaviour in competitive sport systems: An example from championship squash match-play. **Journal of Sports Sciences**, v.14, n.5, p.445-456. 1996.

MÉRAND, R. **L'éducateur face à la haute performance olympique**. Paris, France: Sport et Plein Air. 1977. 80 p.

MOURA, F. A.; MARTINS, L. E. B.; ANIDO, R. O.; BARROS, R. M. L.; CUNHA, S. A. Quantitative analysis of Brazilian football players' organisation on the pitch. **Sports Biomechanics**, v.11, n.1, p.85-96. 2012.

ORTH, D.; DAVIDS, K.; ARAÚJO, D.; RENSHAW, I.; PASSOS, P. Effects of a defender on run-up velocity and ball speed when crossing a football. **European Journal of Sport Science**, v.14, n.Sup. 1. 2014a.

ORTH, D.; DAVIDS, K.; ARAÚJO, D.; RENSHAW, I.; PASSOS, P. Effects of a defender on run-up velocity and ball speed when crossing a football. **European Journal of Sport Science**, v.14, n.Sup.1, p.S316-S323. 2014b.

PASSOS, P.; DAVIDS, K. Learning design to facilitate interactive behaviours in Team Sports. **Revista Internacional de Ciencias del Deporte**, v.11, n.39, p.18-32. 2015.

PASSOS, P.; MILHO, J.; FONSECA, S.; BORGES, J.; ARAÚJO, D.; DAVIDS, K. Interpersonal Distance Regulates Functional Grouping Tendencies of Agents in Team Sports. **Journal of Motor Behavior**, v.43, n.2, p.155-163. 2011.

PINDER, R. A.; DAVIDS, K.; RENSHAW, I.; ARAÚJO, D. Representative Learning Design and Functionality of Research and Practice in Sport. **Journal of Sport & Exercise Psychology**, v.33, n.1, p.146-155. 2011.

POLLARD, R.; REEP, C. Measuring the effectiveness of playing strategies at soccer. **The Statistician**, v.46, n.4, p.541-550. 1997.

REDWOOD-BROWN, A. Passing patterns before and after goal scoring in FA Premier League Soccer. **International Journal of Perfomance Analysis in Sport**, v.8, n.3, p.172-182. 2008.

REEP, C.; BENJAMIN, B. Skill and Chance in Association Football. **Journal of the Royal Statistical Society**, v.131, n.4, p.581-585. 1968.

REILLY, T.; THOMAS, V. A Motion Analysis of Work-Rate in Different Positional Roles in Professional Football Match-Play. **Journal of Human Movement Studies**, n.2, p.87-97. 1976.

SCHAAL, S. Arm and hand movement control. In: M. A. Arbib (Ed.). **The handbook of brain theory and neural networks**. Cambridge, MA: The MIT Press, 2002, p.110-113.

SCHMIDT, R. C.; CARELLO, C.; TURVEY, M. T. Phase Transitions and Critical Fluctuations in the Visual Coordination of Rhythmic Movements Between People. **Journal of Experimental Psychology: Human Perception and Performance**, v.16, n.2, p.227-247. 1990.

SCHMIDT, R. C.; O'BRIEN, B. A.; SYSKO, R. Self-Organization of Between-Persons Cooperative Tasks and Possible Applications to Sport. **International Journal of Sport Psychology**, v.30, n.4, p.558-579. 1999.

SEIFERT, L.; COEURJOLLY, J.-F.; HÉRAULT, R.; WATTEBLED, L.; DAVIDS, K. Temporal dynamics of inter-limb coordination in ice climbing revealed through change-point analysis of the geodesic mean of circular data. **Journal of Applied Statistics**, v.40, n.11, p.2317–2331. 2013.

SEIFERT, L.; WATTEBLED, L.; HERAULT, R.; POIZAT, G.; ADÉ, D.; GAL-PETITFAUX, N.; DAVIDS, K. Neurobiological Degeneracy and Affordance Perception Support Functional Intra-Individual Variability of Inter-Limb Coordination during Ice Climbing. **PLoS ONE**, v.9, n.2, p.e89865. 2014.

SHANNON, C. E. A Mathematical Theory of Communication. **The Bell System Technical Journal**, v.27, n.1, p.379-423, 623-656. 1948.

SILVA, P.; TRAVASSOS, B.; VILAR, L.; AGUIAR, P.; DAVIDS, K.; ARAÚJO, D.; GARGANTA, J. Numerical Relations and Skill Level Constrain Co-Adaptive Behaviors of Agents in Sports Teams. **PLoS ONE**, v.9, n.9, p.e107112. 2014.

STEVENS, P. S. **Patterns in Nature**. Westminster, UK: Penguin Books. 1976. 256 p.

TENGA, A.; HOLME, I.; RONGLAN, L. T.; BAHR, R. Effect of playing tactics on goal scoring in Norwegian professional soccer. **Journal of Sports Sciences**, v.28, n.3, p.237-244. 2010.

TEODORESCU, L. **Théorie et méthodologie des jeux sportifs**. Paris: Les Editeurs Français Réunis. 1977. 246 p.

TRAVASSOS, B.; DUARTE, R.; VILAR, L.; DAVIDS, K.; ARAÚJO, D. Practice task design in team sports: Representativeness enhanced by increasing opportunities for action. **Journal of Sports Sciences**, v.30, n.13, p.1447-1454. 2012.

TURVEY, M. T. Coordination. **American Psychologist**, v.45, n.8, p.938-953. 1990.

VARLET, M.; RICHARDSON, M. J. What Would Be Usain Bolt's 100-Meter Sprint World Record Without Tyson Gay? Unintentional Interpersonal Synchronization Between the Two Sprinters. **Journal of Experimental Psychology: Human Perception and Performance**, v.41, n.1, p.36-41. 2015.

VILAR, L.; ARAÚJO, D.; DAVIDS, K.; BAR-YAM, Y. Science of winning soccer: emergent pattern-forming dynamics in association football. **Journal of Systems Science and Complexity**, v.26, n.1, p.73-84. 2013.

VILAR, L.; ARAÚJO, D.; DAVIDS, K.; BUTTON, C. The Role of Ecological Dynamics in Analysing Performance in Team Sports. **Sports Medicine**, v.42, n.1, p.1-10. 2012.

WALLACE, J. L.; NORTON, K. I. Evolution of World Cup soccer final games 1966-2010: Game structure, speed and play patterns. **Journal of Science and Medicine in Sport**, v.17, n.2, Mar, p.223-228. 2014.

WALLISER, B. **Systèmes et modèles: Introduction critique à l'analyse de systèmes**. Paris: Éditions du Seuil. 1977. 256 p.

YIANNAKOS, A.; ARMATAS, V. Evaluation of the goal scoring patterns in European Championship in Portugal 2004. **International Journal of Perfomance Analysis in Sport**, v.6, n.1, p.178-188. 2006.