Sports Med (2016) 46:1781–1786
DOI 10.1007/s40279-016-0549-2

CURRENT OPINION

The ARCANE Project: How an Ecological Dynamics Framework Can Enhance Performance Assessment and Prediction in Football

Micael S. Couceiro[1,2] · Gonçalo Dias[3] · Duarte Araújo[1] · Keith Davids[4]

Published online: 3 May 2016

Abstract This paper discusses how an ecological dynamics framework can be implemented to interpret data, design practice tasks and interpret athletic performance in collective sports, exemplified here by research ideas within the Augmented peRCeption ANalysis framEwork for Football (ARCANE) project promoting an augmented perception of football teams for scientists and practitioners. An ecological dynamics rationale can provide an interpretation of athletes' positional and physiological data during performance, using new methods to assess athletes' behaviours in real-time and, to some extent, predict health and performance outcomes. The proposed approach signals practical applications for coaches, sports analysts, exercise physiologists and practitioners through merging a large volume of data into a smaller set of variables, resulting in a deeper analysis than typical measures of performance outcomes of competitive games.

✉ Micael S. Couceiro
micael@ingeniarius.pt

1 CIPER, SpertLab, Faculdade de Motricidade Humana, Universidade de Lisboa, Estrada da Costa, Cruz Quebrada, Dafundo, 1499-002 Lisbon, Portugal

2 Ingeniarius, Ltd., Rua Coronel Veiga Simão, Edíficio CTCV, 3° Piso, 3025-307 Coimbra, Portugal

3 Faculty of Sport Sciences and Physical Education, University of Coimbra, 3040-156 Coimbra, Portugal

4 CSER, Sheffield Hallam University, S1 1WB Sheffield, UK

Key Points

The proposed Augmented peRCeption ANalysis framEwork for Football (ARCANE) project highlights how an ecological dynamics theoretical framework can help sport scientists and practitioners to interpret the large volume of data, in order to design practice tasks, as well as to understand and, ultimately, predict athletic performance in football.

The ecological dynamics framework can be useful to assess the existence of dynamic patterns of interpersonal coordination tendencies that emerge between players at various levels of analysis.

1 Introduction

Performance analysis of football teams, whether at an individual or collective level, is of major interest to coaches, sport scientists and performance analysts [1]. A considerable amount of effort has been undertaken in providing a wide range of technological solutions designed to extract statistical data about key aspects of performance during training and competition, including (on-field) players' positioning, frequency of actions completed (such as number of passes, tackles, shots at goal), kinematics of movement, physiological data, and (off-field) nutrition, health and well-being, and recovery from training. Digital technologies, including networks of synchronised cameras [2] or wearable tracking devices with global positioning systems (GPS) and electrocardiography (ECG) systems [3], have resulted in elite, professional sport franchises harnessing the 'Big Data' phenomenon [4].

However, rather than elite sport performance adopting a linear curve towards better performance outcomes, there have been emerging signs of disquiet and concern amongst some academics and practitioners [5, 6]. The term 'datafication' was coined in response to a leading international team sports coach expressing issues with how sport practice, training and pedagogy can exploit the power of data from performance analysis, whilst simultaneously harnessing the experiential knowledge of practitioners [27] (see Greenwood [7]). A major issue expressed by sports practitioners concerns a relative lack of understanding of how to interpret the meaning of large and complex volumes of data and the challenge of implementing sustainable solutions that may be used to enhance performance [6].

This paper presents key ideas behind a relevant theoretical framework developed to support sport scientists on understanding athlete and team performance during competition and training. Here we show how this rationale can help practitioners and administrators in sports programmes to move from a data-driven focus to a data-informed approach to harness the power of new technologies and sports science theory to improve athletic performance. To exemplify this theoretical framework, we present research ideas within the Augmented peRCeption ANalysis framEwork for Football (ARCANE) project, an augmented feedback system for improving team performance in sport for scientists and practitioners.

2 A Theoretical Framework for Interpreting Team Sports Data

Several technologies have been applied to capture collective dynamics in team sports [8]. Among the wide range of technological approaches, such the GPS, radio-frequency identification and computer vision systems [2], wearable technology has by far the greatest potential to provide the most accurate information, in real-time, for coaches and sport scientists [3]. Wearable technology also allows the retrieval of a wider range of data necessary for understanding the overall non-linear dynamics of certain performance modalities. Contrary to the main alternative technology, i.e. computer vision systems, wearable solutions do not require any (human) post-processing after a competitive match. Wearable solutions are completely autonomous and have the potential to provide 'real-time' data during competitive performance concerning each player's physiological data that cannot be retrieved using cameras.

Ecological dynamics integrates concepts from ecological psychology and dynamical systems theory [9] in a theoretical framework grounded by the notion that goal-directed behaviours of individual performers and sports teams are prospectively oriented on the mutuality between performers/teams and a competitive performance environment [9]. In extensive previous work, ecological dynamics has been proposed as a powerful theoretical rationale for identifying the specific patterns of coordination (e.g. interpersonal relations between performers) underpinning the achievement of relevant performance outcomes which avoids the traditional tendencies to focus instead on discrete behaviours and statistics on action frequencies [10]. It advocates that performance goal achievement emerges from non-linear patterns of behaviour that are constrained by intra- and inter-individual couplings between team sport performers in space and time [11]. Ecological dynamics analyses of team sports performance behaviours have sought to clarify how interactions between players and a performance environment provide affordances that can be invitations for actions. Specific affordances can be designed into the practice sessions of coaches, performance analysts and athletes to constrain the emergence of patterns of stability, adaptive variability and transitions in organisational states inherent to sports teams [9, 10, 12–14]. These theoretical ideas have suggested how football analyses can be undertaken by investigating athlete performance, from the perspectives of coordination of actions and physiological data assessment [15]. A large body of research has demonstrated how an ecological dynamics approach can help coaches and sport scientists to identify emergent patterns of intra-individual and inter-individual behaviours from the large amount of data one needs to fully interpret both inter- and intra-personal dynamics in team sports such as football.

The proposed ARCANE project highlights how an ecological dynamics theoretical framework can help sport scientists and practitioners to interpret the large volume of data, in order to design practice tasks, as well as to understand and, ultimately, predict athletic performance in football. It is noteworthy that ARCANE is not designed to 'simply' predict the overall outcome of a competitive match, but rather to systematically estimate, or forecast, what may happen over the subsequent performance iterations based on current retrieved data.

3 Case Study: The ARCANE Project

While current approaches have sought to understand performance in complex sports, such as football, by benefiting from the massive use of technology and data-driven metrics, ARCANE may be seen as a case study to avoid mere 'datafication' in football, by integrating information, technology and theory, as hierarchically described in Fig. 1.

Given the requirements illustrated in Fig. 1, the development of a novel technological wearable solution to analyse players' performance will be of the essence. Even

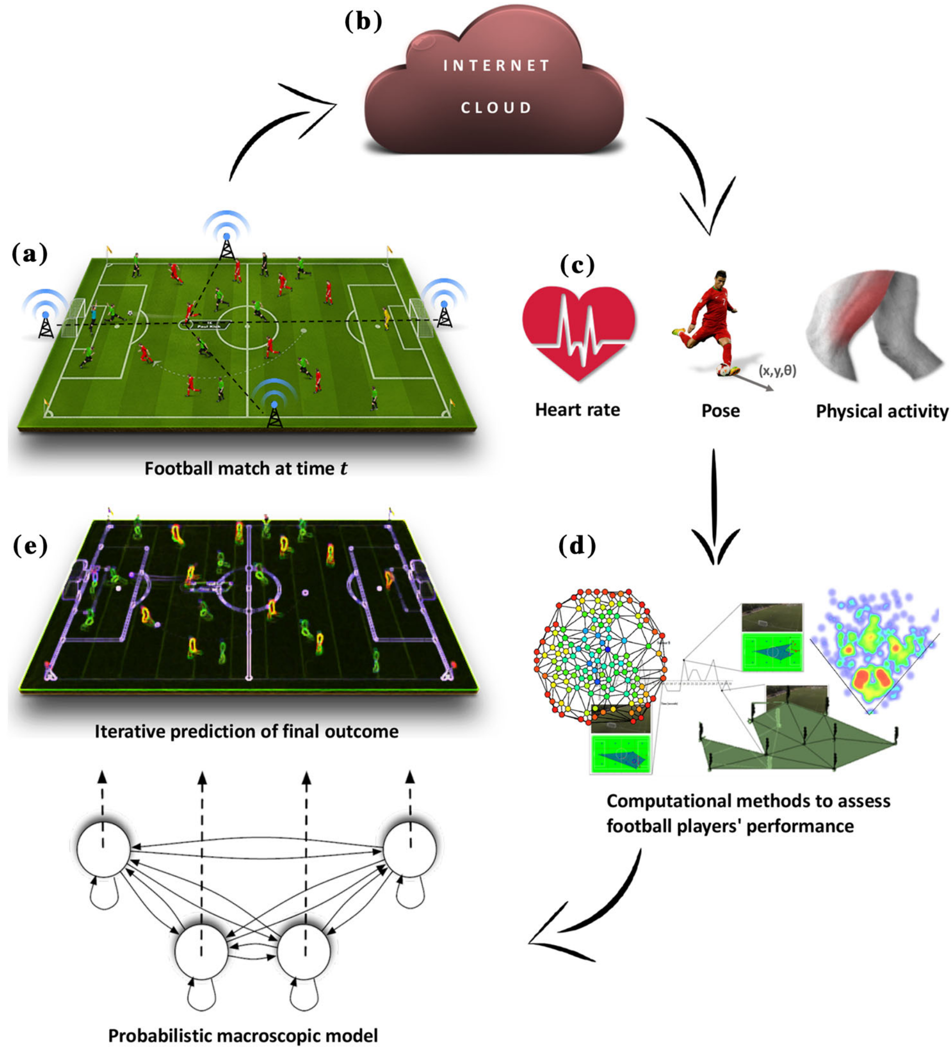

Fig. 1 General overview of the Augmented peRCeption ANalysis framEwork for Football (ARCANE) project: **a** real-time contextual data acquisition; **b** data sent to internet server to benefit from cloud computing; **c** data cleaning and filtering techniques administered to pre-process and compute biosignals and an athlete's pose[1]; **d** pre-processed data feed multiple state-of-the-art performance methods; and **e** methods iteratively feed a macroscopic probabilistic model. [1] In computer sciences, the pose describes the position and orientation of a given object relative to some coordinate system. In our case, we consider the player's pose as his planar (x, y) position and orientation θ (rotation on z axis) in the field

though football has lagged behind other sports, such as Rugby Union and American Football, which benefit from wearables to enhance athletes' performance, the International Football Association Board (IFAB) has already discussed allowing wearable technology to be used during official match play [28].

Figure 2 depicts the overall data acquisition process behind ARCANE. The ARCANE solution is based on ultra-wide band (UWB) wireless technology, in which both mobile devices (players' wearables) and stationary base stations (external landmarks) are Institute of Electrical and Electronics Engineers (IEEE) standard 802.15.4-2011 UWB compliant. Wireless measures are then used as input for the proposed real-time location system (RTS) by benefiting from multilateration techniques[1] [16]. Given that players' movement trajectories are highly dynamic [17], ARCANE also encompasses the design of a fuzzy logic multi-sensor fusion algorithm to provide fault-tolerant information about an athlete's states, following the same theoretical insights provided in our previous studies, modelled as an adaptive mechanism for robot behaviours [18], or as a decision-making tool to prevent disease outbreaks [19]. The positioning system is then locally improved by using inertial measurement sensors within players' wearables. This helps to not only improve players' position estimation using Kalman filters, both in terms of accuracy and precision, but also endows the system with the capacity to estimate players' orientation in the field [20].

To increase the usability of the wearable solution, ARCANE includes physiological variables, by integrating non-invasive physiological sensors, such as heart rate and electromyography, so as to further assist in the decision making of coaches to adequately respond to the dynamics of performance in this team sport. Although the purpose of

[1] Geometric or statistical multilateration techniques are commonly used to combine multiple wireless measurements to obtain position estimates of mobile devices in the vicinity of three or more stationary base stations.

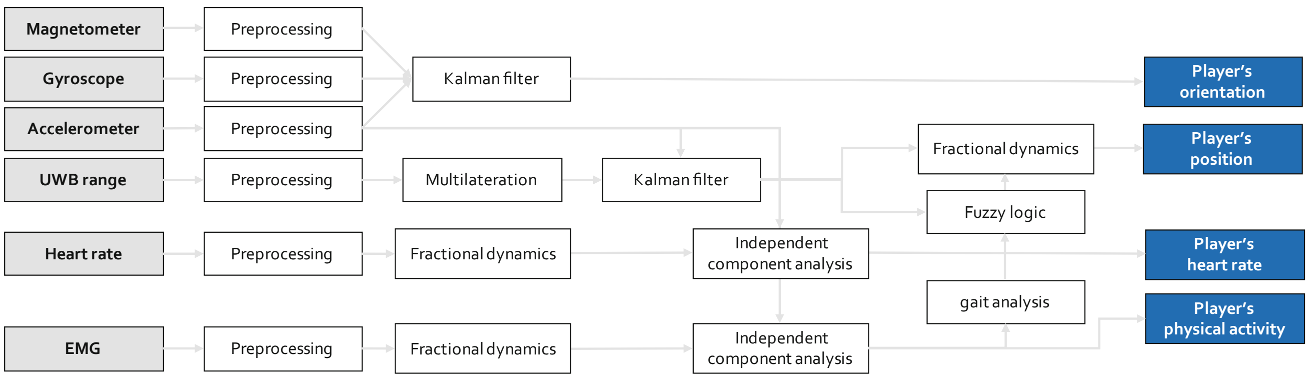

Fig. 2 Augmented peRCeption ANalysis framEwork for Football (ARCANE) data acquisition process. *EMG* electromyography, *UWB* ultra-wide band

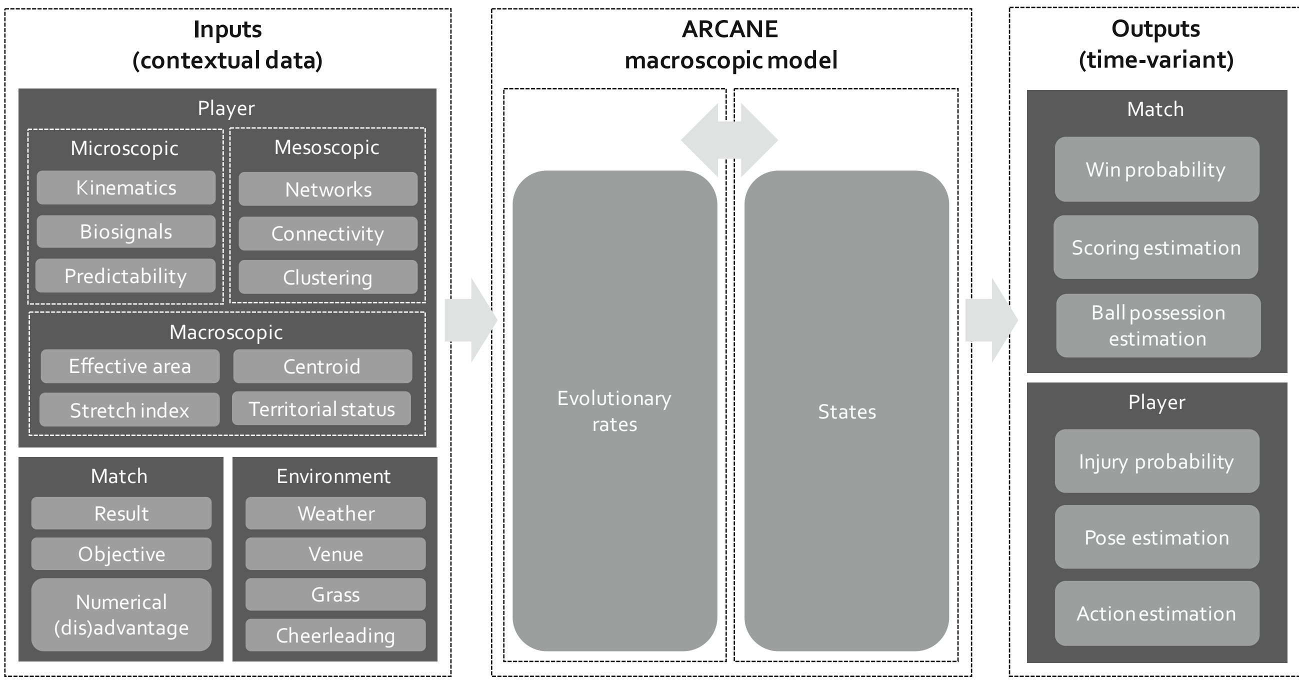

Fig. 3 Augmented peRCeption ANalysis framEwork for Football (ARCANE) probabilistic macroscopic model

ARCANE is to go beyond preventive medical benefits offered to a football player, physiological data are vital inputs of the proposed macroscopic ecological dynamics framework.

With this wide range of data, and as a theoretical framework to model football dynamics, ARCANE encompasses the mathematical formalisation of a framework for online match analysis and prediction (Fig. 3). The general architecture is inspired by a semi-Markov model, following the same principles previously adopted to estimate stochastic processes, such as the performance of swarm robotic teams [21]. The raw data are defined by the inputs from Fig. 2, which are pre-processed (Fig. 2 outputs), and combined with other variables (contextual data about the match and the environment) to feed the semi-Markov model represented in Fig. 3, which then provides a given set of estimated variables (outputs from Fig. 3). The semi-Markov model then comprises multiple states depending on the pre-processed acquired data that include the overall contextual knowledge about a competitive match: from microscopic measures, such as a given athlete's position and physiological data over time with inherent stability and predictability [17], to macroscopic measures, such as an effective area of play [22], including other variables as well, such as the weather and the current state of the game. Although semi-Markov models do not need to be as memoryless as their Markovian counterpart, they are still rather limited in their ability to model football's complexity and non-linear nature. As such, we aim to explore and merge additional tools, such as fuzzy logic (for context awareness) [18], fractional calculus (for memory enhancement) [17] and dynamic Bayesian mixture models (for multiple classifier likelihoods integration) [23].

With these considerations in mind, this project is represented by an interdisciplinary knowledge matrix, which sets it apart from other projects. In this regard, contributions from various emerging methods are inevitable and have been considered in completely different case studies. These methods are justified in this study since they provide an innovative and unique perspective about performance dynamics in football, increasing its predictability and practical applicability within the context of ecological dynamics. So, ARCANE is an interdisciplinary project, which comprises mathematical methods carefully chosen considering the inputs provided by researchers from different disciplinary fields, such as sports sciences, mathematics and engineering, as well end users (e.g. coaches, sport managers and decision makers, etc.). This supports a convergence towards a mathematical representation of a competitive football match, while keeping the ecological perspective acknowledged by sport scientists and football professionals, thus supporting a 'technological reading' of the overall competitive football match. Hence, this approach has practical applications for coaches, sports analysts, exercise physiologists and practitioners in that it merges a large volume of data into a smaller set of variables, providing a more in-depth analysis than can be achieved by using traditional methods (e.g. statistics or notational analysis) to assess a competitive game or through the consideration of performance outcomes only. This acquired information is useful for coaches and a technical support team to the extent that it iteratively provides a 'probabilistic tendency' of what comprises a game over time.

4 Conclusion

Implementing an ecological dynamics perspective, the ARCANE project aims to deeply analyse football teams as open complex systems characterised by adaptive behaviours as a result of continuous dynamic interactions between players [24, 25]. Despite the massive variability and complexity inherent to any particular football match, we consider that ARCANE can be useful to assess the existence of dynamic patterns of interpersonal coordination tendencies that emerge between players at various levels of analysis [26]. Therefore, it is our belief that combining all of these features, which are closely associated with the theoretical assumptions behind the ecological dynamics framework, can lead towards a solution to the 'Big Data' challenge, which can then be measured/assessed through the ARCANE framework using a comprehensive and integrated perspective that goes beyond traditional statistical or notational analyses of a competitive game.

The ARCANE project settles on the fact that an ecological dynamics perspective may contain general principles to understand the overall non-linear dynamics of football [10], at the 'micro-level' of individual changes in athletes' behavioural evolution over time or the 'macro-level' predictions of the final outcomes of competitive football matches. These principles underpin the process of adaptation to a specific performance environment, providing a platform for sport players to develop expertise.

Compliance with Ethical Standards

Funding This work was supported by the Portuguese Foundation for Science and Technology (FCT) under the grant SFRH/BPD/99655/2014, Ingeniarius, Ltd., CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, Laboratory of Expertise in Sport (SpertLab), and Centre for Sports Engineering Research (CSER).

Conflict of interest Micael Couceiro is the Chief Executive Officer (CEO) of Ingeniarius, Ltd., a company that provides custom outsource consulting and research services for technology-based companies and industrial units in the several fields of engineering, including robotics, image processing, computer science and sports engineering. Gonçalo Dias, Duarte Araújo and Keith Davids declare that they have no conflicts of interest relevant to the content of this article.

References

1. Clemente FM, Couceiro MS, Martins FML, et al. An online tactical metrics applied to football game. Res J Appl Sci Eng Technol. 2013;5(5):1700–19.
2. Barros RML, Misuta MS, Menezes RP, et al. Analysis of the distances covered by first division Brazilian soccer players obtained with an automatic tracking method. J Sports Sci. 2007;6:233–42.
3. Ermes M, Parkka J, Cluitmans L. Advancing from offline to online activity recognition with wearable sensors. Conf Proc IEEE Eng Med Biol Soc. 2008;2008:4451–4.
4. Millington B. The datafication of everything: towards a sociology of sport and Big Data. Social Sport J. 2015;32(2):140–60
5. Travassos B, Araújo D, Davids K, et al. Expertise effects on decision-making in sport are constrained by requisite response behaviours—a meta-analysis. Psychol Sport Exerc. 2013;14(2):211–9.
6. Williams S, Manley A. Elite coaching and the technocratic engineer: thanking the boys at Microsoft! Sport Educ Soc. 2014;1–23. doi:10.1080/13573322.2014.958816
7. Greenwood DA. Informational constraints on performance of dynamic interceptive actions [PhD thesis]. Brisbane: Queensland University of Technology; 2014.
8. Baca A, Dabnichki P, Heller M, et al. Ubiquitous computing in sports: a review and analysis. J Sports Sci. 2009;27(12):1335–46.
9. Araújo D, Davids K, Hristovski R. The ecological dynamics of decision making in sport. Psychol Sport Exerc. 2006;7(6):653–76.
10. Travassos B, Davids K, Araújo D, et al. Performance analysis in team sports: advances from an ecological dynamics approach. Int J Perf Anal Sport. 2013;13(1):83–95.

11. McGarry T, Anderson DI, Wallace SA, et al. Sport competition as a dynamical self-organizing system. J Sports Sci. 2002;20(10):771–81.
12. Vilar L, Araújo D, Davids K, et al. Science of winning soccer: emergent pattern-forming dynamics in Association Football. J Syst Sci Complex. 2013;26:73–84.
13. Silva P, Garganta J, Araújo D, et al. Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. Sports Med. 2013;43(9):765–72.
14. Passos P, Araújo D, Davids K. Self-organization processes in field-invasion team sports. Sports Med. 2013;43(1):1–7.
15. Renshaw I, Davids K, Shuttleworth R, et al. Insights from ecological psychology and dynamical systems theory can underpin a philosophy of coaching. Int J Sport Psychol. 2009;40(4):540–602.
16. Munoz D, Lara FB, Vargas C, et al. Position location techniques and applications. London: Academic; 2009.
17. Couceiro MS, Clemente FM, Martins FM, et al. Dynamical stability and predictability of football players: the study of one match. Entropy. 2014;16(2):645–74.
18. Couceiro MS, Machado JAT, Rocha RP, et al. A fuzzified systematic adjustment of the robotic Darwinian PSO. Rob Auton Syst. 2012;60(12):1625–39.
19. Couceiro MS, Figueiredo CM, Luz MA, et al. Zombie infection warning system based on Fuzzy decision-making. In: Smith? R. Mathematical modelling of zombies. Ottawa: University of Ottawa Press; 2014.
20. Mohamed AH, Schwarz KP. Adaptive Kalman filtering for INS/GPS. J Geod. 1999;73(4):193–203.
21. Couceiro MS. Evolutionary robot swarms under real-world constraints [PhD thesis]. Coimbra: Institute of Systems and Robotics, University of Coimbra; 2014.
22. Clemente FM, Couceiro MS, Martins FM. Towards a new method to analyze the soccer teams tactical behaviour: measuring the effective area of play. Indian J Sci Technol. 2012;5(12):3792–801.
23. Faria DR, Premebida C, Nunes U. A probabilistic approach for human everyday activities recognition using body motion from RGB-D images. In: The 23rd IEEE international symposium on robot and human interactive communication (RO-MAN 2014); 25–29 Aug 2014; Edinburgh. New York: IEEE; 2014. pp. 732–737.
24. Vilar L, Araújo D, Davids K, et al. The role of ecological dynamics in analysing performance in team sports. Sports Med. 2012;42(1):1–10.
25. Gama J, Passos P, Davids K, et al. Network analysis and intra-team activity in attacking phases of professional football. J Perf Anal Sport. 2014;14(3):692–708.
26. Vilar L, Araújo D, Travassos B, et al. Coordination tendencies are shaped by attacker and defender interactions with the goal and the ball in futsal. Hum Mov Sci. 2014;33(1):14–24.
27. Maharaj R. Game of drones: Cheika's welcome call for gut feel in science-dominated rugby coaching. The Guardian. 2015 Apr 3. http://www.theguardian.com/sport/blog/2015/apr/03/game-of-drones-cheikas-welcome-call-for-gut-feel-in-science-dominated-rugby-coaching. Accessed 17 Apr 2016.
28. Svetlik J. It's coming home: how wearable tech is about to change football. Wearable. 2015 Aug 7. http://www.wareable.com/fitness-trackers/how-wearable-tech-is-about-to-change-football. Accessed 17 Apr 2016.