COMPLEX SYSTEMS IN SPORT

INTERNATIONAL CONGRESS 2017

LINKING THEORY AND PRACTICE

BARCELONA, 5th — 6th OCTOBER 2017,
FC BARCELONA STADIUM "CAMP NOU"

Organized by:

INEFC
Generalitat de Catalunya

Complex Systems in Sport

Hosted by:

BARÇA INNOVATION HUB

www.barcainnovationhub.com

frontiers Abstract Book

Complex Systems in Sport, International Congress

Linking Theory and Practice

Edited by Carlota Torrents, Pedro Passos and Francesc Cos

ISBN: 978-2-88945-310-8

DOI: 10.3389/978-2-88945-310-8

October 5th 2017 – October 6th 2017, FC Barcelona Stadium "Camp Nou", Barcelona .

In this 5th edition of the Complex Systems in Sport Congress it is time to evaluate where we are and get a consensus about where to go in the near future. The science of complex systems is evolving very fast and society is requesting for practical applications of our research, a non easy endeavour that obviously keep us really busy and involved.

Complex Systems in Sport is still a baby learning to walk. It started its development in areas like biomechanics, motor learning and control, and during the last two decades evolved fastly diversifying into fields like decision making, performance and game analysis, talent identification, sport injuries or thought dynamics with outstanding research published in top journals. We hope to be able to provide in the future enough research evidences and rigorous mathematical models for changing the dominant statical paradigm of sport science, still based on timeless inferential statistics. In our humble opinion, future efforts should be oriented towards a) trying to formulate deductive mathematical models and theories which should more rigorously channelize the experimental and empirical research, and b) extend the realm of Complex Systems in Sport to other areas (e.g., molecular and cellular biology in sports) by collaborating with specialists which already model and analyse these levels of organization using the complex systems toolbox.

We are very grateful to the join collaboration of Complex Systems in Sport Research Group, FC Barcelona and INEFC for organizing this congress and we hope to contribute with our scientific work to do a step forward in the understanding of sport related phenomena. Sport scientists and also sport professionals can benefit of the complex systems approach because there is nothing more practical than a good theory.

Natàlia Balagué

Table of Contents

ABSTRACTS PLENARY SESSIONS

Unpredictability in Competitive Environments

Robert Hristovski

Complex Systems in Sport Research Group, Faculty of Physical Education, Sports and Health, University of Saints Cyril and Methodius, Skopje, Macedonia
robert_hristovski@yahoo.com

Collective sports comprise of cooperative and competitive organizational processes in which players have to be predictable for teammates and sufficiently diverse and unpredictable for opponents in order to satisfy the goal constraints. In highly stable, repetitive and thus predictable (cooperative or non-cooperative) environments the adaptive system may converge to a minimum unpredictability by minimizing the diversity of accessible patterns of functional behaviour. However, sport competition, akin to life itself, is not a highly stable and repetitive process based on negotiating stable environment. It creates conditions where highly demanding non-cooperative behaviour of the environment is rather rule than an exception. In such stochastically changing and non-cooperative environments, systems (players and teams) must develop high behavioural unpredictability potential to increase their fitness to the competitive environment. This means that the adaptation process rests on a tendency of permanent increase of the unpredictability potential which affords the ultimate goal, the survival (winning) of the system in sports environments. This state of affairs suggests that performance may be conceptualized in terms of unpredictability/diversity potential and that its development can be understood by the juxtaposition of three principles of adaptive systems: (a) relativity of organism–environment unpredictability; (b) satisficing diversity/unpredictability potential; and (c) tendency towards non-decreasing unpredictability/diversity.

(a) *Relativity of organism–environment unpredictability*: Collective sports adaptation is a process of becoming fit to one's environment. Becoming fit means that the environment becomes more informative and less constraining for the player/team and, on the other hand, the player/team becomes less informative, and thus more unpredictable for the environment. The relativity of organism-environment unpredictability is based on the conservation of bio-motor information principle (Hristovski, 1989). This principle says that performance variables, including motor abilities (effectivities), such as power, agility, speed, strength, endurance, etc., may be treated as entropy measures forming a state space in which training induces conversion of entropy into information. By increasing the effectivities, and thus, the accessibility of diverse perception-action couplings, players lower the entropy of her/his couplings (what and how to do it) with the environment. This increases the informativeness of the environment as it becomes less constraining. Conversely, seen from the perspective of the environment/opponents, this process makes player's or team's actions less predictable and informative. It enhances their behavioural unpredictability potential (Figure 1). Thus, there is a relativity of the perceived effects of the training process as seen from the perspective of the player/team or from the perspective of the environment/opponents. This co-adaptive process, however, is not limitless and is constrained by the second principle, which is a juxtaposition of the law of requisite variety (Ashby, 1956) and the satisficing principle (Simon, 1956).

(b) *Satisficing diversity/unpredictability potential*: This principle poses that the system (players and teams) develop the diversity/unpredictability potential asymptotically converging to some level that is considered sufficient. This process is based on permanent co-adaptation of the player/team—environment/opponent system that sets the asymptotic level of convergence. The level of satisfactory unpredictability performance potential, then, acts as a slow variable that regulates the faster evolving processes and effectivities based on specific socio-biological properties and processess such as degeneracy (Seifert et al., 2013), synergy, synchrony, exploration (Ric et al., 2016), etc., which, in turn, stabilize the development of unpredictability/diversity potential. Hence, setting of challenging environments and levels of satisfactory unpredictability potential is a crucial practice constraint to be manipulated during this co-adaptive process.

(c) *Tendency towards non-decreasing unpredictability/diversity*: In its own right, co-adaptivity is underpinned by the principle of non-decreasing diversity/unpredictability, which states that the system (player/team) develops a reactive force to any perturbation from the environment/opponent which reduces the previous state of diversity/unpredictability. This type of entropic force drives the adaptive response of the system (Figure 2). Hence, the co-adaptivity at multiple time scales and levels may be defined as a competition of two forces: (a) tendency to decrease opponent's opportunities of action and increasing their informativeness or predictability (suppression); and (b) tendency to increase one's own potential diversity/unpredictability of action (flourishing). Interesting consequences for emergence of social interactions stem from these principles. In general, non-decreasing unpredictability/diversity often is possible only through social endeavour. Therefore, it is possible that the tendency of non-decreasing diversity/unpredictability is the driving force of formation of social structures such as sports teams. In other words, we hypothesize that this principle drives the system towards forming social couplings of players. In this view, the non-decreasing unpredictability/diversity underlines the creation and stability of teams. Teams exist to

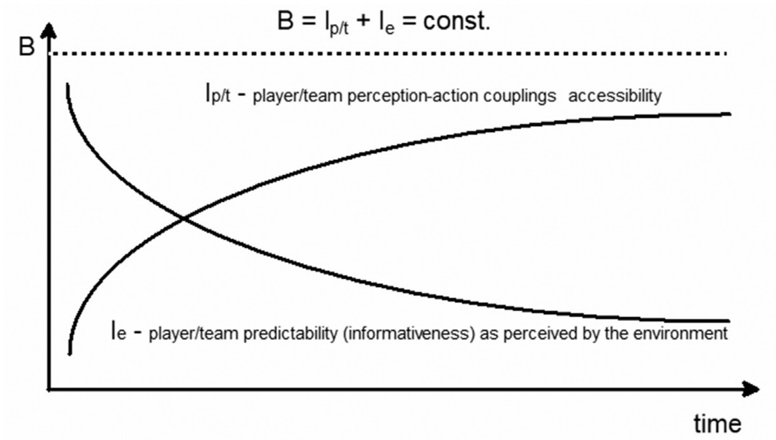


FIGURE 1: The compensatory relation between the Ip/t and Ie. Dotted line B = const.

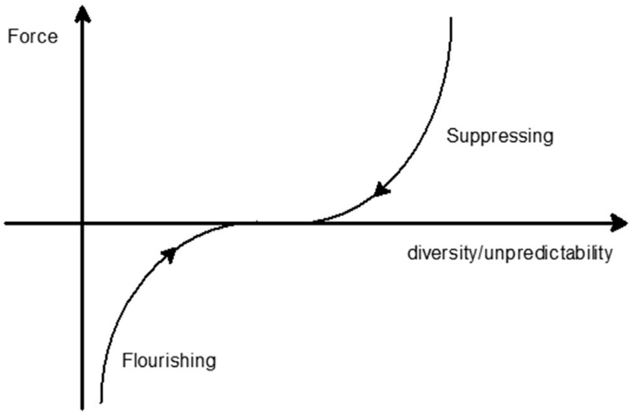


FIGURE 2: Opponents/environment tends to act in such a way as to suppress the state of diversity/unpredictability of players/teams and *vice versa*, the later tend to increase these properties in order to maintain or increase the satisficing level.

the degree to which their members contribute to its non-decreasing diversity/ unpredictability. This result among the others possibly points to the collective level that has to be emphasized during the training of team sports, because it is the level that is being spontaneously formed by the entropic force. The creation of "zones of perception-action abundance" may show beneficial in enhancing the player/team diversity/unpredictability potential. These zones may be defined as regions in multidimensional constraints space that maximize the functional diversity for certain goal constraints.

REFERENCES

Ashby, W. R. (1956). *An Introduction to Cybernetics*. London: Chapman & Hall.

Hristovski, R. (1989). On the dynamics of bio-motor actions as state changes in a human bio-motor field. (In Serbian). *Fizicka Kultura* 43, 59–63.

Ric, A., Hristovski, R., Gonçalves, B., Torres, L., Sampaio, J., and Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *J. Sports Sci.* 34, 1723–1730. doi: 10.1080/02640414.2015.1136068 PMID:26758958

Seifert, L., Button, C., and Davids, K. (2013). Key properties of expert movement systems in sport: an ecological dynamics perspective. *Sports Med.* 43, 167–178. doi: 10.1007/s40279-012-0011-z PMID:23329604

Simon, H. A. (1956). Rational choice and the structure of the environment. *Psychol. Rev.* 63, 129–138. doi: 10.1037/h0042769

Principles of Coordination: Synergies of Synergies!

J. A. Scott Kelso[1,2]

[1]Center for Complex Systems and Brain Sciences, Florida Atlantic University, Boca Raton, FL, United States

[2]Intelligent Systems Research Centre, Ulster University, Ireland

kelso@ccs.fau.edu

Prolegomenon: As a result of scientific research conducted in laboratories around the world, principles of self-organizing coordination dynamics have been shown to govern patterns of coordination (a) within a moving limb and between moving limbs; (b) between the articulators during speech production; (c) between limb movements and tactile, visual and auditory stimuli;(d) between people interacting with each other spontaneously or intentionally; (e) between humans and avatars; (f) between humans and other species, as in riding a horse; (g) between babies and mobiles; and (h) within and between the neural substrates that underlie the coordinated behavior of human beings as measured using MEG, EEG, and fMRI (Kelso et al., 2013; Fuchs and Kelso, 2018). The principles embrace perception, development, learning, adaptation, decision-making, intentional change, and basic social interactions. The evidence suggests that law of coordination in complex, neurobehavioral dynamical systems deal with collective properties that emerge from the interactions among many parts and processes. So, how did all this come about?

Background: Many moons ago, my colleagues and I (including many students) set out to understand (if not solve) the problem of coordination in living things. Movement, the animated, living movement of human beings was the test field chosen in part because of a love for sports, and the performing arts. The first step was to identify the significant units of biological coordination and their key properties. This is not a trivial problem nor can it be assumed *a priori*: animate movement is not made up merely of a list of component parts such as molecules, muscles, neurons, and brains, but rather has to do with how these many parts function as a unitary ensemble when human beings engage in the multitude of tasks they typically perform, some at a very high level of skill. The second step was to explain how, that is through which laws and mechanisms, such units are assembled, how they adapt, persist and change as circumstances change, and *why* they are significant units in the first place. We found that the significant units of coordination (maybe of life itself) are *functional* synergies or *coordinative structures*. “Synergies of meaningful movement” (to use the philosopher-biologist Maxine Sheets-Johnstone’s coinage) have been hypothesized as important for motor control for over 100 years but until our research in the late 1970s and early 1980s, the evidence was anecdotal or restricted to the so-called “pre-wired” rhythmical activities such as locomotion and respiration. Much work has been done since, of course, and books written (e.g., Kelso, 1995; Latash, 2008; Sheets-Johnstone, 1999/2011). So, why are synergies preferred over other candidates such as currently popular circuits and networks? Only synergies embrace variability in structure and function. Only synergies handle the fact that many different components can produce the same function, and that the same components may be assembled to produce multiple functions. Synergies or coordinative structures are not restricted to muscles; they have been identified at many scales from the cellular and neural, to the cognitive and social (Kelso, 2009a). The deeper reasons for synergies as the basic units of biological organization are that they are the result of two elemental forces, evolution and self-organization. When cooperation occurs between two or more entities and that cooperation proves to be functionally advantageous, *synergistic selection* is deemed to occur. *Self-organization*—the discovery of emergent cooperative phenomena in natural systems—has also been demonstrated in coordinated movement and the brain. For the latter, self-organizing principles are expressed in terms of informationally coupled dynamical systems (coordination dynamics). A key concept is the so-called *order parameter* or *collective variable*, a term borrowed from physics that expresses cooperative behavior in systems with many degrees of freedom (Haken, 1977/83). It turns out that order parameters (OPs) are important for understanding *any* kind of coordination, from the brain to players in teams, from ballet dancers to championship rowers, because they constitute the *content* of the underlying dynamics. OPs cannot be assumed, but have to be identified in the particular system or activity being studied or described. For example, relative phase, frequency ratios, amplitudes, etc., can act as order parameters for relatively low-dimensional systems. In high-dimensional systems like the brain, time-dependent spatial *modes* have been shown to capture the coordination dynamics in both experiment and theory. Instabilities are a means of order parameter identification as well as a source of testable predictions. Not only are OPs expressions of emergent patterns among interacting components and processes, they in turn modify the very components whose interactions create them. This confluence of top-down and bottom-up processes results in *circular causality*, an essential concept in coordination dynamics. In short, unlike the laws of motion of physical bodies, *laws of coordination are expressed as the flow of coordination states produced by functional synergies or coordinative structures.* The latter span many different kinds of things and participate in many processes and events at many scales. In their most elementary form, coordination laws are governed by symmetry (and symmetry breaking) and arise from nonlinear coupling among the very components, processes, and events that constitute the coordinative structure on a given level of description.

Developments: Can coordinative structures be learned? Of course they can. Not only do they underlie the process of learning, they dictate the very nature of the changes that occur as a result of learning (Kostrubiec et al., 2012 for review). In coordination dynamics, *learning* is shown to be the creation and stabilization of new synergies. New synergies arise from old synergies through competitive or cooperative mechanisms. Do synergies adapt? Of course they do. Recent empirical and modeling work on interpersonal coordination (Nordham et al., in press) shows the form such *adaptation* takes: on the one hand, the component parts adapt to produce the collective pattern that people spontaneously adopt; on the other hand, the pattern formed modifies the component parts and their persistence (circular causality!). Modeling reveals that the key to adaptation is making the parameters of the interacting components dynamic, i.e., not fixed but time-dependent. Synergies are often used to mean cooperation. However, once their governing dynamics is revealed, it is clear that synergies possess both cooperative and competitive aspects. The coordination dynamics that underlies such dual, complementary tendencies is *metastable* and *chimera-like* (Kelso and Engström, 2006; Kelso, 2014; Tognoli and Kelso, 2014). For example, recent work (Zhang et al., submitted) has studied spatiotemporal coordination in groups of eight agents (people) in real time. An interesting result, relevant perhaps for team sports, is that a critical value of *diversity* exists between the subgroups that form among coordinating individuals, separating régimes of integration and segregation. Complex systems research often deals with very large or very small number of components. The intermediate scale typical of teams is "messy," but revelatory: it shows that synergies are not rigid coordination states; they are flexible and metastable. Finally, it is often remarked that team cohesion relies on everyone being "on the same wavelength." New results using brain-to-brain coupling measures indicate that (dyadic) team coordination is associated with increased inter-brain coherence of beta and gamma rhythms in time intervals where subjects exchange key information in ecologically valid task settings (Dodel et al., submitted).

Conclusion: A theory of coordination is fundamentally about softly assembled, self-organized, evolutionarily based synergies expressed in the language of informationally coupled dynamical systems (coordination dynamics). It deals with relationships, connectedness, communication, coupling, and context. *At the level of team sports, goal-directed synergies of meaningful movement are the basis of coordination.* Sports science might pay special attention to synergies, because according to coordination dynamics, they are the key to successful and highly skillful performance, as well as to clinical outcomes following injury or disease. Finding applications of coordination dynamics, a fairly new laboratory-based science of coordination (Kelso, 1992, 2009b)—itself a combination of Theory, Experiment, Analysis, and Modeling (TEAM)—presents sports science with a challenge. It is a bit like asking, what the applications of classical or quantum mechanics might be when they were first put forward. No one had the slightest idea. Yet, the applications of these ideas changed the world. (Such statements are not meant to be pretentious, only to make the point that the research findings and concepts of coordination dynamics described here, may or may not be applicable to sports, dance, coaching, teaching, rehabilitation, and so forth. There are plenty of signs that they will, e.g., Teques et al., 2017, but this is still an open issue.) In Joan Miró's paintings of black and white with splashes of color, the calligraphic strokes look like they could be the traces and trajectories of a football team. As in Miró's forms, the beautiful game generates forms which in turn suggest space and movement and further forms—the game develops its own direction on multiple time scales, apparently out of conscious control. Making sense of the gestures and movements of others (synergies of meaningful movement of team mates?) and making oneself intelligible by way of one's own synergies of meaningful movement is the basis of who we are. Maybe of team sports too. Synergies of synergies. Up and down, within and between, through and through.

Acknowledgements

The work described herein was supported by the US National Institute of Mental Health (MH080838), the Chaire d'Excellence Pierre de Fermat, and the Davimos Family Endowment for Excellence in Science.

REFERENCES

Dodel, S., Tognoli, E., and Kelso, J. A. S. (submitted). Social coordination and degeneracy in the brain.

Fuchs, A., and Kelso, J. A. S. (2018). "Coordination dynamics and synergetics: from finger movements to brain patterns and ballet dancing," in *Complexity and Synergetics*, eds S. Mueller, et al. (Heidelberg: Springer).

Haken, H. (1977/83). *Synergetics, an Introduction: Non-Equilibrium Phase Transitions and Self-Organization in Physics, Chemistry and Biology*. Berlin: Springer.

Kelso, J. A. S. (1992). "Coordination dynamics of human brain and behavior," in *Springer Proceedings in Physics*, Vol. 69 (Berlin: Heidelberg), 223-234.

Kelso, J. A. S. (1995). *Dynamic Patterns: The Self Organization of Brain and Behavior*. Cambridge, MA: The MIT Press.

Kelso, J. A. S. (2009a). Synergies: atoms of brain and behavior. *Adv. Exp. Med. Biol.* 629, 83–91. doi: 10.1007/978-0-387-77064-2_5

Kelso, J. A. S. (2009b). "Coordination dynamics," in *Encyclopedia of Complexity and System Science*, ed. R. A. Meyers (Heidelberg: Springer), 1537–1564.

Kelso, J. A. S. (2014). "The dynamic brain in action: coordinative structures, criticality and coordination dynamics," in *Criticality in Neural Systems*, eds D. Plenz and E. Niebur (Mannheim: John Wiley & Sons), 67–106.

Kelso, J. A. S., Dumas, G., and Tognoli, E. (2013). Outline of a general theory of behavior and brain coordination. *Neural Netw.* 37, 120–131. doi: 10.1016/j.neunet.2012.09.003 PMID:23084845

Kelso, J. A. S., and Engström, D. A. (2006). *The Complementary Nature*. Cambridge, MA: The MIT Press.

Kostrubiec, V., Zanone, P.-G., Fuchs, A., and Kelso, J. A. S. (2012). Beyond the blank slate: routes to learning new coordination patterns depend on the intrinsic dynamics of the learner—experimental evidence and theoretical model. *Front. Hum. Neurosci.* 6:212. doi: 10.3389/fnhum.2012.00222

Latash, M. (2008). *Synergy*. Oxford, New York: Oxford University Press.

Nordham, C. A., Tognoli, E., Fuchs, A., and Kelso, J. A. S. (in press). How interpersonal coordination affects individual behavior (and *vice-versa*): experimental analysis and adaptive HKB model of social memory. *Ecol. Psychol.*

Sheets-Johnstone, M. (1999/2011). *The Primacy of Movement*, 2nd Edn. Amsterdam/Philadelphia: John Benjamins.

Teques, P., Araújo, D., Seifert, L., del Campo, V. L., and Davids, K. (2017). "The resonant system: linking brain-body-environment in sport performance," in *Progress in brain research: Sport and the Brain: The Science of Preparing, Enduring and Winning winning. Part B*, Vol. 234, 1st Edn, eds M. Wilson, V. Walsh, and B. Parkin (Amsterdan: Academic Press).

Tognoli, E., and Kelso, J. A. S. (2014). The metastable brain. *Neuron* 81, 35–48. doi: 10.1016/j.neuron.2013.12.022 PMID:24411730

Zhang, M., Kelso, J. A. S., and Tognoli, E. (submitted). Critical diversity: united or divided states of social coordination.

Cons-Training in Team Sports

Rafel Pol[1,2]

[1]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
[2]Real Club Celta de Vigo, Vigo, Spain
polrafel@gmail.com

During the last decade, integrated training methodologies have become popular in both the theory and practice of team sports, but there is still a limited understanding about the integration principles that lead players and teams to develop adequately their performance. Balagué et al. (2014) have distinguished between linear and non-linear integration models in relation with sports training. Linear integration models assume that athletes interact with themselves and with their environment in a proportional, fixed, and invariable in time way. On the other hand, the dynamic and non-linear integration model, based on dynamical systems principles (Kelso, 1995) and ecological psychology (Gibson, 1979), assumes that athletes self-organize with their environment in a non-proportional and dynamic way. The emergent individual and collective synergies that characterize the players and teams sport behavior are then a product of the interaction among personal and environmental constraints (Sampaio and Maçãs, 2012). Based on Newell's model (Newell, 1986), three types of constraints (personal, task, and environmental) are distinguished and recognized under the so-called constraints-led perspective (Renshaw et al., 2011). The manipulation of task constraints has been widely used in sport for training purposes (Davids et al., 2013). Under the name of Cons-Training, we re-conceptualize Newell's constraint classification model, and expand the constraints-led perspective reorganizing the types of constraints in nested levels and timescales. The Cons-Training methodology considers that (a) task constraints can be either environmentally imposed or emerge from the interaction between personal/team and environmental constraints, (b) personal and environmental constraints are formed by nested/correlated structures and processes operating at different timescales, and (c) environmental constraints acting at similar timescales should be critically manipulated to challenge continuously the team performance. During the lecture, the theoretical basis of the Cons-Training will be presented together with some practical applications to football.

REFERENCES

Balagué, N., Torrents, C., Pol, R., and Seirullo, F. (2014). Entrenamiento integrado. Principios dinámicos y aplicaciones. *Apunts. Educació Fisica i Esport* 116, 60–68. doi:10.5672/apunts.2014-0983.es.(2014/2).116.06

Davids, K., Araújo, D., Correia, V., and Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exerc. Sport Sci. Rev.* 41, 154–161. doi: 10.1097/JES.0b013e318292f3ec

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. USA: Houghton Mifflin Company.

Kelso, J. A. S. (1995). *Dynamic Patterns: The Self-Organization of Brain and Behavior*. Cambridge: MIT Press.

Newell, K. M. (1986). Constraints on the development of coordination. *Mot. Dev. Child. Asp. Coord. Control.* 34, 341–360.

Renshaw, I., Davids, K., and Salvelsbergh, G. (2011). *Motor Learning in Practice: A Constraints-Led Approach*. London: Roudledge.

Sampaio, J., and Maçãs, V. (2012). Measuring tactical behavior in football. *Int. J. Sports Med.* 33, 395–401. doi: 10.1055/s-0031-1301320

A Short Journey into the Dimensions of Performance in Team Sports

Jaime Sampaio

Research Center in Sports Sciences, Health Sciences, and Human Development (CIDESD), CreativeLab Research Community, Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal
ajaime@utad.pt

Performance analysis in team sports is probably one of the hottest topics in sports sciences. At the present time, sports scientists are struggling to integrate the technological advances, that allowed to develop data sets so large and complex that changed the standard requirements for processing, with theoretical and applied perspectives that can fit a purpose. In fact, the characteristics of big data (volume, velocity, variety, variability, and veracity) (Demchenko et al., 2014) seem to have changed the focus of searching for theories of sports performance that can help understanding mechanisms underpinning interventions to an "all you can measure and describe with no effort" process, that seems to provide little help in moving sports sciences forward and has been resulting in easy proliferation of almost redundant and ungrounded publications in peer review journals. One of the most interesting frameworks to organize team sports research under a tactical perspective considers different interactive landscapes to start using big data, by capturing and describing players and teams' performance characteristics considering macro, meso, and micro levels of interaction (Grehaigne et al., 1999, Grehaigne and Godbout, 2013). Macro level studies mostly use variables such as teams and sector-specific centroid, distance between centroids, teams' areas and/or teams' length and width, later processed with different non-linear tools such as relative phase or entropy-based procedures (Memmert et al., 2017). At a meso level of analysis, research is focused on every interaction based on more than two opposing or same team players, but less than the whole team. Research done in this level of analysis tends to use small-sided games situations either to test the effects of interventions of to describe the effects from the manipulation of constraints (Sampaio and Maçãs, 2012; Gonçalves et al., 2016). Finally, at the micro-level, studies can describe 1 × 1 situations focusing on parameters related to the attacker or defender success (Duarte et al., 2012). The different levels of analysis (micro, meso, and macro) are obviously interrelated and present the same core principles at different time and space scales of coordination (Davids et al., 2005; Ric et al., 2016). This characteristic might be very important to start understanding better the dose-responses in each level of analysis, but also to start investigating how players respond to dynamic changes when the levels are present in the same training tasks. In the past, the direct decomposition of expected match behaviour into less complex situations, seem to have failed in provide the relevant contextual information, diminishing the potential practice transfer to competition scenarios (Travassos et al., 2012). Therefore, future pathways in science can include different approaches taken in order to design and test the effects of practice tasks that explore how players adapt to dynamic changes in levels of interaction. Accordingly, there are several possibilities of combining these dynamic changes into consistent training methods designed either for learning or performing across a sports season or to be used in each developmental stage. Finally, coach intervention in each level of interaction seems also to be a key determinant of success and, therefore, the frequency and the focus of intervening in the tasks are worthwhile of being explored.

REFERENCES

Davids, K., Araújo, D., and Shuttleworth, R. (2005). "Applications of dynamical systems theory to football," in *Science and Football V*, eds T. Reilly, J. Cabriy, and D. Araújo (London: Routledge, Taylor & Francis), 537–550.

Demchenko, Y., Laat, C. D., and Membrey, P. (2014). Defining architecture components of the big data ecosystem. *Paper Presented at the 2014 International Conference on Collaboration Technologies and Systems (CTS)*, Bloomington, Indiana and Dayton, Ohio, USA.

Duarte, R., Araujo, D., Davids, K., Travassos, B., Gazimba, V., and Sampaio, J. (2012). Interpersonal coordination tendencies shape 1-vs-1 sub-phase performance outcomes in youth soccer. *J. Sports Sci.* 30, 871–877. doi: 10.1080/02640414.2012.675081 PMID:22545768

Gonçalves, B., Marcelino, R., Torres-Ronda, L., Torrents, C., and Sampaio, J. (2016). Effects of emphasising opposition and cooperation on collective movement behaviour during football small-sided games. *J. Sports Sci.* 34, 1346–1354. doi: 10.1080/02640414.2016.1143111 PMID:26928336

Grehaigne, J., and Godbout, P. (2013). "Collective variables for analysing performance in team sports," in *Routledge Handbook of Sports Performance Analysis*, eds T. McGarry, P. O'Donoghue, and J. Sampaio (Oxfordshire: Taylor & Francis) 101–114..

Grehaigne, J. F., Godbout, P., and Bouthier, D. (1999). The foundations of tactics and strategy in team sports. *J. Teach. Phys. Educ.* 18, 159–174. doi: 10.1123/jtpe.18.2.159

Memmert, D., Lemmink, K. A. P. M., and Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Med.* 47, 1–10. doi: 10.1007/s40279-016-0562-5

Ric, A., Hristovski, R., Goncalves, B., Torres, L., Sampaio, J., and Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *J. Sports Sci.* 34, 1723–1730. doi: 10.1080/02640414.2015.1136068 PMID:26758958

Sampaio, J., and Maçãs, V. (2012). Measuring tactical behavior in football. *Int. J. Sports Med.* 33, 395–401. doi: 10.1055/s-0031-1301320

Travassos, B., Duarte, R., Vilar, L., Davids, K., and Araújo, D. (2012). Practice task design in team sports: representativeness enhanced by increasing opportunities for action. *J. Sports Sci.* 30, 1447–1454. doi: 10.1080/02640414.2012.712716 PMID:22871067

Differential Learning As a Turbo for Body and Brain

W. I. Schöllhorn[1], K. M. Newell[2]

[1]University of Mainz, Mainz, Germany
[2]University of Georgia, Athens, GA, United States
schoellw@uni-mainz.de

For a long time, learning, training, and therapy were associated with the need for endless repetitions of practice and copying biomechanically supported, putative movement prototypes for the action at hand. Despite the intuitiveness of individual movements and the impossibility of their identical repetition most learning approaches are still based on personal-independent guidelines that are accompanied with numerous types of error corrections. Contradictions of the reality with respect to two phenomena led to a fundamental rethinking of the misleading interpretation of errors in the learning process. On the one hand, non-linear pattern recognition methods not only allowed for the recognition of top athletes in sports (Bauer and Schöllhorn, 1997) and persons in everyday movements on the basis of their movements but also allowed the identification of emotional states and the grade of fatigue during their movements (Janssen et al., 2008). On the other hand, beside the negligible probability of repeating a movement identically, a problem is that individual movement characteristics change continuously in an adaptive fashion (Horst et al., 2017). With the first problem, the traditional prototypes for training are challenged fundamentally, with the second problem the place of repetition in these models raises many questions. More intriguing, due to the continuous adaptation of our movement structures we are continuously confronted with something new, namely, uncertainty. Traditionally, we in effect just hope that the future situations will not deviate too far from the one's we trained for. It follows that our traditional learning approaches rarely prepare for us new events. In order to cope with such uncertainty, nature takes advantage of our ability to interpolate between two known states from earliest childhood. Children's learning of movement forms is characterized by exploration rather than by repetition. Exploration means variability that can be expressed in differences between two subsequent events. Differential learning (DL) takes advantage of this kind of learning by providing a corresponding theoretical basis that explains such phenomena and transfers consequences to learning and retention across ages and domain content areas. Principles of the dynamics of living systems and neurophysiology (Kelso, 1995) pointed to the constructive influence of fluctuations. Beside extensive descriptions and re-interpretations of the variance phenomena in movement (Davids et al., 2006), the differential learning approach (Schöllhorn, 2000) was instigated to consider noise as an active instrument ("order from noise") by enhancing the existing variance in movements by means of stochastic perturbations within the frame of stochastic resonance. Correspondingly, all types of interventions in learning, training, and therapy can be considered as sources for noise with different amount and character (Schöllhorn et al., 2006). Because of the individuality of movement patterns and their situative dependence on emotions, fatigue, or music the optimum noise for each athlete has to be found according to the situation. In the narrow sense of DL, the optimum noise led to "no repetitions" and "no corrections." Other learning approaches were considered as DL in a broader sense that also includes several repetitions dependent on the individual and the individual's situation. Numerous investigations in different sports with athletes of different ages and different performance levels not only have shown significantly more rapid acquisition rates and higher performance levels immediately after the intervention, but also delivered increased learning rates following the intervention. Initially, mainly applied in the training of different sports techniques, the same advantages are meanwhile found in tactical training, music teaching, in the handwriting of first graders, in the physiotherapy and occupational therapy of stroke patients, in fall prevention, and even in the education of dentists. In accordance with Bertalanffy's general system theory for the study of principles common to all complex entities, the suggested theoretical basis was expressed in a quite abstract form to be able to apply the principles independent of their substance, type, or spatial or temporal scale of existence. Analogously, a transfer of the DL ideas towards shorter time scales led to similar phenomena. Additive noise during sitting, standing, or walking revealed significantly higher performances not only in the movement level but also in cognitive tasks. After extensive confirmation of the original predictions on the behavioral level, recent findings indicate similar phenomena at the brain level. DL is demonstrably responsible for brain conditions that differ significantly from those of other learning processes and can thus be used for a wide range of learning areas (Henz and Schöllhorn, 2016). Similar findings in meditation research and the field of therapy (Henz and Schöllhorn, 2017) point to the scope of the approach.

REFERENCES

Bauer, H. U., and Schöllhorn, W. I. (1997). Self-organizing maps for the analysis of complex movement patterns. *Neural Process. Lett.* 5, 193–199. doi: 10.1023/A:1009646811510

Davids, K., Bennett, S. and Newell, K. M. (2006). *Movement system variability*. Champaign, IL, USA: Human Kinetics.

Henz, D., and Schöllhorn, W. I. (2016). Differential training facilitates early consolidation in motor learning. *Front. Behav. Neurosci.* 10:199. doi: 10.3389/fnbeh.2016.00199

Henz, D., and Schöllhorn, W. I. (2017). EEG brain activity in dynamic health Qigong training: same effects for mental practice and physical training? *Front. Psychol.* 8:154. doi: 10.3389/fpsyg.2017.00154 PMID:28223957

Horst, F., Eekhoff, A., Newell, K. M., and Schöllhorn, W. (2017). Intra-individual gait patterns across different time-scales as revealed by means of a supervised learning model using kernel-based discriminant regression. *PLoS ONE* 12:e0179738. doi: 10.1371/journal.pone.0179738 PMID:28617842

Janssen, D., Schöllhorn, W. I., Lubienetzki, J., Fölling, K., Kokenge, H., and Davids, K. (2008). Recognition of emotions in gait patterns by means of artificial neural nets. *J. Nonverbal Behav.* 32, 79–92. doi: 10.1007/s10919-007-0045-3

Kelso, J. A. S. (1995). *Dynamic Patterns*. Cambridge: MIT Press.

Schöllhorn, W. I. (2000). Applications of systems dynamic principles to technique and strength training. *Acta Academiae Olympiquae estoniae* 8, 67–85.

Schöllhorn, W. I., Beckmann, H., Michelbrink, M., Sechelmann, M., Trockel, M., and Davids, K. (2006). Does noise provide a basis for the unification of motor learning theories? *Int. J. Sport Psychol.* 37, 34–42.

ABSTRACTS INVITED SESSIONS

The Role of Self-Perception and Self-Awareness on Injury Prevention

N. Balagué[1], A. Gibert[2,3], R. Pol[4,5], D. Medina[6], R. Hristovski[7]

[1]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), Universitat de Barcelona (UB), Barcelona, Spain
[2]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), Universitat de Lleida (UdL), Lleida, Spain
[3]TecnoCampus Mataró, Barcelona, Spain
[4]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
[5]Real Club Celta de Vigo, Vigo, Spain
[6]Sports Science and Medical Department, Complex Systems in Sport Research Group, FC Barcelona, Barcelona, Spain
[7]Complex Systems in Sport Research Group, Faculty of Physical Education, Sport and Health, Ss Cyril and Methodius University of Skopje, Skopje, Macedonia
nbalague@gencat.cat

The effectivity of programmes designed to prevent sport injuries have not improved over recent decades (Mendiguchia et al., 2012); and, according to some reports, have even worsen (e.g., hamstring or ACL in soccer) (Ekstrand et al., 2016). The objective of this presentation is to explain that this situation may improve through:

(a) A better understanding of the underlying principles that explain the emergence of "non-contact" sport injuries

(b) The development of athlete's self-awareness and their greater responsibility over workload regulation

(a) Previous assumptions about the aetiology of sport injuries are mostly based on linear, upward causality relationships among microscopic and macroscopic musculoskeletal structures (e.g., the relation of tensile forces at sarcomere level and muscle strain). This assumption ignores three main principles:

(i) new properties and functions emerge at micro, meso, and macro biological levels and the variations in isolated microscopic structures cannot explain macroscopic events,

(ii) personal risk factors interact with environmental risk factors at different levels and timescales so that a standard manoeuvre may trigger a severe injury,

(iii) the susceptibility to injuries may change not only as a result of bottom-up influences, but also top-down (from social and psychological levels to musculoskeletal structures),

Multifactorial injury models, usually based on a static and rigid conception of the interaction and integration among risk factors or fixed patterns, cannot particularly explain sport injuries which are non-proportional to their "causes," i.e. product of common sport actions performed repeatedly without visible harmful effects. In general, too much focus is usually put on the so-called "inciting events" which are not causing but simply constraining the emergence of sport injuries.

(b) Respect the usually ignored top-down effects in injury prevention programmes, to point out that:

(i) As a consequence of changes at very short timescales of personal and environmental constraints, the susceptibility to injuries may increase unexpectedly; and thus, workloads should be continuously adapted on the basis of athlete's states,

(ii) the early detection of individual symptoms related to musculoskeletal susceptibility (as coordinative changes or initial inflammatory responses) is crucial for adapting training and competition workloads,

(iii) with an adequate education, athletes have a unique capacity to integrate the information from all psychobiological levels,

(iv) special focus should be put on the education of slowly changing personal constraints as athlete's value system and the corresponding correlated driven goals at different timescales. When athlete's intended goals surpass the immediate individual abilities, the risk of injury increases,

(v) pedagogical tools should be created to develop self-perception and self-awareness at early ages to guarantee a productive and save sport life.

In conclusion, the development of programmes addressed to develop self-perception and self-awareness of athletes, and the participation of athlete's in the co-design of training and competition workloads, seems suitable to complement the current prevention sport injuries programmes.

REFERENCES

Ekstrand, J., Waldén, M., and Hägglund, M. (2016). Hamstring injuries have increased by 4% annually in men's professional football, since 2001: a 13-year longitudinal analysis of the UEFA Elite Club injury study. *Br. J. Sports Med.* 50, 731–737. doi: 10.1136/bjsports-2015-095359

Mendiguchia, J., Alentorn-Geli, E., and Brughelli, M. (2012). Hamstring strain injuries: are we heading in the right direction? *Br. J. Sports Med.* 46, 81–85. doi: 10.1136/bjsm.2010.081695

A Nonlinear Pedagogical Approach to Teaching Movement Skills in Physical Education

Jia Yi Chow[1], Clara Wee Keat Tan[2], Sock Miang Teo-Koh[1], Chris Button[3], Benjamin Tan[2], Manu Kapur[4], Corliss Zhi Yi Choo[1]

[1]Physical Education and Sports Science, National Institute of Education, Nanyang Technological University, Singapore, Singapore

[2]Physical Education and Sports Teacher Academy, Ministry of Education, Singapore, Singapore

[3]School of Physical Education, Sport and Exercise Sciences, University of Otago, Dunedin, New Zealand

[4]Learning Sciences and Higher Education, ETH Zurich, Zurich, Switzerland

jiayi.chow@nie.edu.sg

Physical Education in schools provides an excellent platform for children to acquire movement behaviours that prepare them to meet a myriad of movement challenges in sports and physical activities. Practitioners are always searching for optimal approaches to deliver coaching or teaching in order to maximize skill acquisition. Increasingly, practitioners see the need to recognize the complex and dynamic interactions that occur between the individual, task, and environmental constraints during learning (Renshaw et al., 2010; Chow et al., 2011). Nonlinear Pedagogy, underpinned by Ecological Dynamics, potentially provides a suitable pedagogical approach to encourage exploratory learning that is student-centred and exploratory in nature (Chow et al., 2016). Key pedagogical principles relating to representativeness, manipulation of constraints, awareness of focus of attention instructions, task simplification, and the functional role of noise can encourage exploratory learning that helps build twenty-first century competencies in our learners (Chow, 2013; Chow et al., 2016). To explore the efficacy of a Nonlinear Pedagogy approach, two schools at the Secondary One level were recruited for this study. Four classes within each school were randomly assigned to either a Nonlinear (i.e., incorporating the key pedagogical principles of nonlinear pedagogy as highlighted above) or Linear (i.e., incorporating typical repetitive and prescriptive practices where movement form is emphasized) conditions. Four teachers were involved (two from each school), and the same teachers taught both the Nonlinear and Linear condition classes to ensure that there is control in terms of eliminating the potential impact of the teacher on the effectiveness of the two conditions. Thus, specifically, each teacher taught one Nonlinear class and one Linear class. Students had to undergo a 10-week intervention programme, where they were required to learn game skills within an invasion game (soccer). Performance outcome data (e.g., number of goals scored, number of successful passes, and possession time) were measured during pre-test, post-test, retention, and transfer tests. In addition, semi-structured interviews and focus group discussions were conducted with the teachers and students, respectively to augment the understanding of the students and teachers experiences in relation to the respective interventions. Preliminary results from one of the schools highlight certain implications of the impact of Nonlinear Pedagogy in teaching and learning for both students and teachers. Findings thus far show that Nonlinear Pedagogy seems promising with reference to discrete performance data and that it is as good as Linear Pedagogy in promoting the attainment of performance outcome relating to invasion games (soccer in this context). Both students in the Nonlinear and Linear conditions showed similar improvements for all performance outcome data between test sessions. Specifically, students from both pedagogical approaches improved between the pre and post tests and were able to adapt to the transfer test conditions. This is perhaps interesting as typically, a less prescriptive and exploratory pedagogical approach (such as Nonlinear Pedagogy) may be deemed as requiring more time for effective learning to emerge (Lee et al., 2014). Importantly, qualitative interview data from teachers and students provided valuable insights into how Nonlinear Pedagogy can work in a setting for practitioners and suggest that there are differences between the two pedagogical approaches in terms of level of enjoyment and the learning processes experienced by the participants. Feedback from teachers indicated that the Nonlinear Pedagogy approach allowed for innovation and creativity among students. One teacher specifically highlighted that, "*The cues don't restrict the student in a certain way… The student is given time to adjust his movement to execute the desired outcome*." Teachers also felt that the Nonlinear Pedagogy approach provided a more authentic experience for more active learning, and hence created a sense of satisfaction and ownership. That is in contrast to the Linear Pedagogy approach where one teacher commented: "*Fast but less room for discovery. It's focused, but the width and the depth of cognitive thinking may not be there*." This seems to reflect what the students felt as well. A student from the Nonlinear Pedagogy condition shared that, "*We would change the skill. Take the skill and downgrade to our standard… Create your own move. Adapt it*." Whereas those who were in the Linear Pedagogy approach were trying to follow a certain "optimal" movement pattern prescribed by the teacher. These preliminary findings provide some insights for practitioners when designing instructions for skill acquisition. Moving forward, more in-depth analysis on the game play patterns is needed to provide greater knowledge about the teaching and learning processes that underlie both Nonlinear and Linear pedagogical approaches.

Acknowledgements

This research is funded by the Education Research Funding Programme (OER 21/14 CJY), National Institute of Education (NIE), and Nanyang Technological University, Singapore. The views expressed in this abstract are the author's and do not necessarily represent the views of NIE.

REFERENCES

Chow, J. Y. (2013). Nonlinear learning underpinning pedagogy: evidence, challenges and implications. *Quest* 65, 469–484. doi: 10.1080/00336297.2013.807746

Chow, J. Y., Davids, K., Button, C., and Renshaw, I. (2016). *Nonlinear Pedagogy in Skill Acquisition: An Introduction*. London: Routledge.

Chow, J. Y., Davids, K., Hristovski, R., Araújo, D., and Passos, P. (2011). Nonlinear pedagogy: learning design for self-organizing neurobiological systems. *New Ideas Psychol.* 29, 189–200. doi: 10.1016/j.newideapsych.2010.10.001

Lee, M. C. Y., Chow, J. Y., Komar, J., Tan, C. W. K., and Button, C. (2014). Nonlinear pedagogy: an effective approach to cater for individual differences in learning a sports skill. *PLoS ONE* 9:e104744. doi: 10.1371/journal.pone.0104744 PMID:25140822

Renshaw, I., Davids, K., and Savelsbergh, G. J. P. (2010). *Motor Learning in Practice. A Constraints-Led Approach*. London: Routledge.

Internet of Sports: The Rise of Smart Devices for Performance Assessment and Prediction in Sport

Micael S. Couceiro[1,2], Duarte Araújo[2], Keith Davids[3]

[1]Ingeniarius Ltd., Rua Coronel Veiga Simão, Coimbra, Portugal
[2]Ciper, Universidade de Lisboa, SpertLab, Faculdade de Motricidade Humana, Cruz Quebrada, Portugal
[3]CSER, Sheffield Hallam University, Sheffield, United Kingdom
micael@ingeniarius.pt
daraujo@fmh.ulisboa.pt
k.davids@shu.ac.uk

Performance analysis, whether for individual (e.g., golf) or collective (e.g., football) sports, is of major interest to coaches, sport scientists, and performance analysts (Clemente et al., 2013; Couceiro et al., 2014). Nevertheless, it encompasses multiple scientific and technological issues and challenges, which can be overcome by the guidance from the ecological dynamics theoretical framework (McGarry, 2009; Vilar et al., 2012; Passos et al., 2017). Such guidance can direct and consequently reduce the considerable amount of effort that has been undertaken for providing a wide range of ever-improving technological solutions designed to extract data about key aspects of performance during training and competition, including kinematics of movement and physiological data. While we have been witnessing outstanding technological advancements in sports devices over the past decade, led by market leaders such as *Sportvision*, *Catapult*, *Nike+*, *Science & Motion Sports*, *Synergy Sports*, and many others, the high costs, the inherent setup complexity, or the lack of contextual sensitivity, have constrained their wide-ranging applicability. Moreover, due to the data-driven nature of most state-of-the-art sports devices, it has been extremely challenging to ensure an on-the-fly performance analysis and, consequently, significantly boost the deployment of such technologies in competitive environments. This is a collateral drawback from technological advances in sports, as they radically amplify the volume and variety of data in circulation, as well as the velocity at which data moves, giving rise to the *Big Data* challenge (Millington and Millington, 2015). In light of these limitations, issues and existing challenges, this session overviews a set of disruptive sport devices, encompassing technology, frameworks, and mathematical models. This talk aims to describe the hardware and software developments undertaken by *Ingeniarius*, in close collaboration with the *Faculty of Human Kinetics of the University of Lisbon* (FMH), *University of Coimbra* (UC), the *Institute of Systems and Robotics* (ISR-UC), the *Polytechnic Institute of Coimbra* (IPC), and *Sheffield-Hallam University* (SHU), highlighting and assessing the benefits of these devices by experimentally validating them under multiple competitive environments. This shared effort between academia and industry led to the development of novel solutions designed for performance assessment and prediction in sports (e.g., Couceiro et al., 2016). Examples of such designed devices were applied to golf (*InPutter*), football (*TraXports*), and all-purpose human kinematic analysis (*FatoXtract*), where the sampling rate, accuracy, and precision of the acquired data, as well as the physical properties of the hardware, were chosen considering the specificities of the sport task and the need to ensure its representative design. While current approaches have sought to understand performance in dynamic sports by benefiting from the massive use of technology and data-driven metrics, the adopted approaches were tailored to avoid mere "datafication" in sports, by integrating information, technology, and theory, as hierarchically presented in the next figure. All sport devices are classified as internet-connected solutions, acquiring a large volume of data, in real-time, that undergoes task-related pre-processing routines, followed by both compression and encryption preceding the communication with the server. The server encompasses a database, task-related post-processing routines, and user-centred browser-based applications fully developed in *HTML5* and *WebGL*, thus being cross-compatible with most browsers, operating systems, and devices. Task-related post-processing routines are twofold: (i) to compute high-level algorithms (e.g., mathematical modelling, classification architectures, etc.) for extracting and predicting key features of athletic performance (e.g., athlete profiles, trajectory estimation, heart rate, etc.); and (ii), to support data visualization provided through the browser-based applications with the aim of enabling decision-makers (e.g., coaches) to grasp difficult concepts or identify subtle patterns. The latter partially depends on the former, while both are built upon the ecological dynamics theoretical framework necessary to interpret the performance of the athletes under a given task on-the-fly and, to some extent, predict specific sport-related outcomes. The proposed technologies, frameworks, and mathematical models present practical applications for coaches,

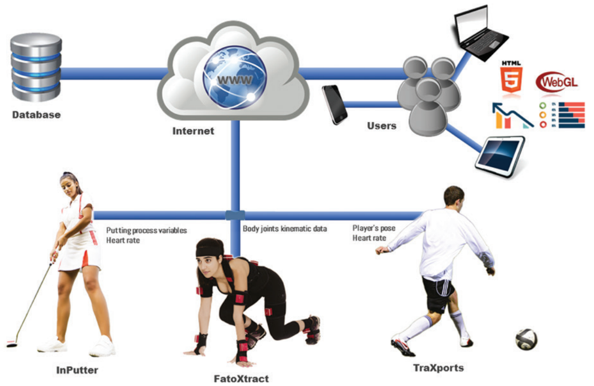


FIGURE 1: Adopted communication architecture of the developed internet-connected sports devices.

sports analysts, exercise physiologists, and practitioners. Such applications merge large volumes of data, with inherently complex patterns, into sets of contextualized variables, resulting in a deeper and broader analysis than traditional approaches.

REFERENCES

Clemente, F. M., Couceiro, M. S., Martins, F. M., and Mendes, R. (2013). An online tactical metrics applied to football game. *Res. J. Appl. Sci. Eng. Technol.* 5, 1700–1719.

Couceiro, M. S., Dias, G., Araújo, D., and Davids, K. (2016). The ARCANE project: how an ecological dynamics framework can enhance performance assessment and prediction in football. *Sports Med.* 46, 1781–1786. doi: 10.1007/s40279-016-0549-2 PMID:27139724

Couceiro, M. S., Martins, F. M., Clemente, F. M., Dias, G., and Mendes, R. (2014). On a fuzzy approach for the evaluation of golf players. *Maejo Int. J. Sci. Technol.* 8, 86–99.

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

Millington, B., and Millington, R. (2015). 'The datafication of everything': toward a sociology of sport and big data. *Sociol. Sport J.* 32, 140–160. doi: 10.1123/ssj.2014-0069

Passos, P., Araújo, D., and Volossovitch, A. (2017). *Performance Analysis in Team Sports*. London: Routledge.

Vilar, L., Araújo, D., Davids, K., and Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Med.* 42, 1–10. doi: 10.2165/11596520-000000000-00000 PMID:22149695

Antiphase Crew Rowing on Water: A First Case Study

L. S. Cuijpers, H. J. de Poel

Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, Netherlands
l.s.cuijpers@gmail.com

Introduction: In crew rowing, agents need to mutually coordinate their movements to achieve optimal performance (De Poel et al., 2016). Traditionally, rowers aim to achieve perfect synchronous (in-phase) coordination. Somewhat counterintuitively, however, crew rowing in an *antiphase* pattern (i.e., alternating strokes) would actually be mechanically more efficient: it diminishes the within-cycle surge velocity fluctuations of the boat, thereby reducing hydrodynamic drag and hence power losses with 5–6% (Brearley et al., 1998; De Brouwer et al., 2013; Cuijpers et al., 2015; De Poel et al., 2016; Greidanus et al., 2016). However, from coordination dynamics an antiphase pattern is expected to be less stable, especially at high stroke rates such as in racing, which may even lead to transitions to the more stable in-phase pattern (Haken et al., 1985). Recent laboratory studies in which rower dyads performed antiphase crew coordination on two mechanically coupled ergometers have provided promising results (De Brouwer et al., 2013; Cuijpers et al., 2015; De Poel et al., 2016). However, counter to ergometer rowing, rowing on-water also requires handling of the oars and boat movements in three dimensions, such as lateral balance and forward speed. Furthermore, the boat has actual forward speed. Therefore, the next step in this endeavour is to examine antiphase crew rowing and associated boat movements *on water*. Here, we report results of the first test case.

Method: Two experienced male rowers (age 32 and 34 years; length 1.93 and 1.94 m; mass 91.8 and 91.3 kg; rowing experience 11 and 7 years, of which 4 years in the same crew) rowed four trials of 1,000 m rowing in in-phase and antiphase crew coordination at 20 and 30 strokes per minute (*spm*). The rowers were instructed to maintain a steady state over the length of the course and started rowing approximately 100 m before the start of the trail to achieve their steady state. Next, they were instructed to maintain a similar power output (i.e., by maintaining the same heart rate) per stroke rate condition. For all trials, a quad (i.e., a four-person boat) was used to provide sufficient space for the oars not to collide in the antiphase condition; the two middle seats were left empty. Oar angles and movements of the boat were collected at 200 Hz using a customized measurement system including waterproof and a three-axial accelerometer-gyroscope sensor (see Cuijpers et al., 2015). The 1,000 m times were clocked with a stopwatch. For each of the four trials, the absolute error and variability of relative phase were

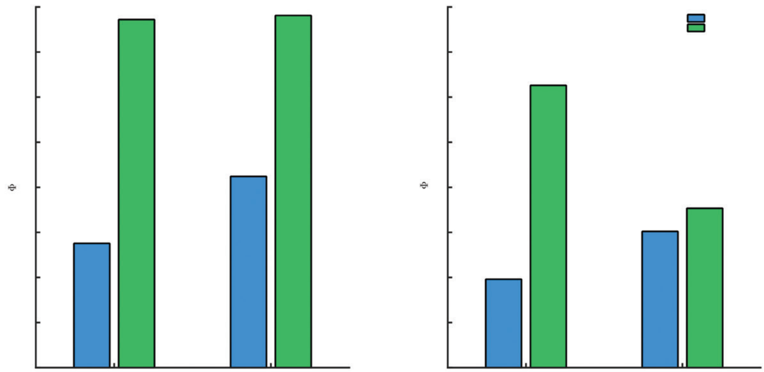


FIGURE 1: Absolute error (left panel) and variability (right panel) of crew coordination in in-phase and antiphase at 20 and 30 spm.

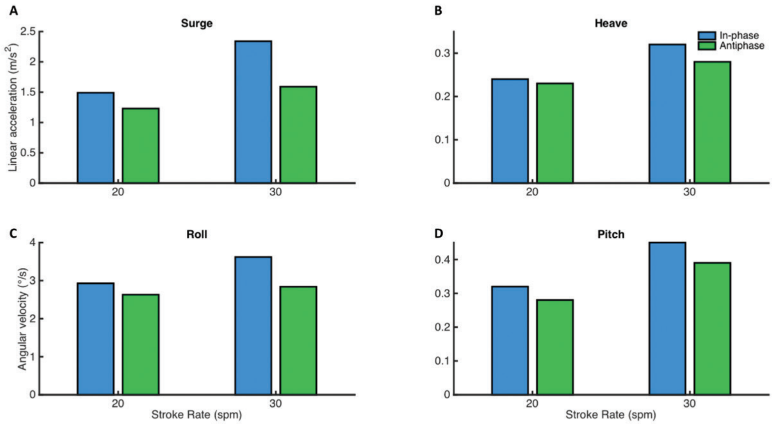


FIGURE 2: Movements of the boat in terms of **(A)** surge, **(B)** heave, **(C)** roll, and **(D)** pitch in- and antiphase at 20 and 30 spm.

calculated as coordinative measures. Variability of surge and heave (accelerometers), and roll and pitch (gyroscopes) were adopted as measures of boat movements.

Results: As expected, larger values of absolute error and variability of relative phase were found for antiphase than in-phase (Figure 1). Nevertheless, the antiphase pattern seemed sufficiently stable to perform on-water, even more so at 30 spm. In fact, at the higher stroke rate of 30 spm antiphase coordinative variability *de*creased to a level that barely differed from that of in-phase. Surge (reflecting fluctuations in boat velocity) was much lower in antiphase compared to in-phase (Figure 2A), especially at the higher stroke rate of 30 spm. Next to that, Figures 2B–D show that also heave, roll and pitch of the boat reduced for the antiphase compared to the in-phase trials, especially at 30 spm. Still, the 1,000 m times were faster for the regular in-phase than in the "new" antiphase rowing pattern (4:27 vs. 4:38 m for 20 *spm*; 3:56 vs. 4:10 m for 30 *spm*, respectively). Note however that the rowers *never* performed this antiphase rowing pattern before.

Conclusion: Together, the results of this case study verify the drastic reduction of surge speed fluctuations of the shell for antiphase compared to in-phase crew rowing. Moreover, heave, pitch, and roll also reduced, which may even imply extra benefits of antiphase rowing in terms of drag and balance (Wing and Woodburn, 1995). Importantly, next to in the lab (Cuijpers et al., 2015) also on water the between-agent antiphase pattern appeared sufficiently stable to maintain at high movement rate. This is quite promising, given that this was only the very first time these experienced rowers rowed in antiphase. As is obvious, there is room for optimization of the antiphase coordination performance, which likely enhances the currently observed boat speed (as measured by the 1,000 m times). As such it seems worthwhile to further investigate (the optimization of) the potential benefits of antiphase rowing.

REFERENCES

Brearley, M. N., De Mestre, N. J., and Watson, D. R. (1998). Modelling the rowing stroke in racing shells. *Math. Gaz.* 82, 389–404. doi: 10.2307/3619885

Cuijpers, L. S., Zaal, F. T. J. M., and De Poel, H. J. (2015). Rowing crew coordination dynamics at increasing stroke rates. *PLoS ONE* 10:e0133527. doi: 10.1371/journal.pone.0133527 PMID:26185987

De Brouwer, A. J., De Poel, H. J., and Hofmijster, M. J. (2013). Don't rock the boat: how anti- phase crew coordination a ects rowing. *PLoS ONE* 8:e54996. doi: 10.1371/journal.pone.0054996

De Poel, H. J., De Brouwer, A. J., and Cuijpers, L. S. (2016). "Crew rowing: an archetype of interpersonal coordination dynamics," in *Interpersonal Coordination and Performance in Social Systems*, eds P. Passos, K. Davids, and J. Y. Chow (New York, NY, USA: Routledge), 140–153.

Greidanus, A. J., Delfos, R., and Westerweel, J. (2016). Drag and power-loss in rowing due to velocity fluctuations. *Procedia Eng.* 147, 317–323. doi: 10.1016/j.proeng.2016.06.299

Haken, H., Kelso, J. A. S., and Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biol. Cybern.* 51, 347–356. doi: 10.1007/BF00336922 PMID:3978150

Wing, A. M., and Woodburn, C. (1995). The coordination and consistency of rowers in a racing eight. *J. Sports Sci.* 13, 187–197. doi: 10.1080/02640419508732227

Learning Design for Athletes and Sports Teams Considered As Complex Adaptive Systems

Keith Davids

CSER, Sheffield Hallam University, Sheffield, United Kingdom
k.davids@shu.ac.uk

In recent years, the theory of ecological dynamics has led to scientists and sports practitioners to conceptualise athletes and sports teams as complex adaptive systems. What does such a conceptualisation imply for the design of practice programmes in sport? Key ideas in ecological dynamics suggest that sport practitioners could understand that athletes continually use information to regulate their actions. Information to organise actions may be provided by directions, verbal instructions, and feedback of a coach during highly structured practices. Or information to regulate actions may be found during the exploration of a practice environment by an athlete or sports team during activities with less structure and direction provided by coaches. Careful task constraints manipulation by sports practitioners can help athletes learn to couple their actions to perceptual information and use affordances (opportunities or invitations for action) that are available to achieve their task goals in performance environments. This presentation proposes that a major aim of a coach is to design relevant practice tasks for each individual athlete or team from the landscape of affordances available in a performance environment. This individualised approach to sports training emphasises the need for task designs that help athletes search relevant parts of the affordance landscape in practice. A range of constraints can be manipulated to guide athlete search during practice in relevant fields of the affordance landscape. A major implication from this conceptualisation of athletes and teams as complex adaptive systems is that coaches could consider themselves designers of learning environments.

Assessing Competitive Between-Athlete Coordination

H. J. de Poel, O. Noorbergen

Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, Netherlands
h.j.de.poel@umcg.nl

Introduction: During multi-agent sports performance, interactions between the athletes involved give rise to collective patterns that can be assessed at a common level of analysis, e.g., at pair level, team level, or overall match level. Next to cooperative interactions between teammates, direct competition between opponents is ubiquitous and fundamental to sport. The aim of this contribution is to illustrate how competitive interactions entail collective patterns that deviate from those of cooperative interaction. To assess between-agent interactions and patterns, the theoretical perspective of coordination dynamics offers expedient analysis tools. Given a relevant dynamical model of coupled oscillators (Haken et al., 1985) this approach is often adopted as a basis for analysis of dyadic (i.e., two-person or two-team) sports situations. Previous research on interpersonal movement coordination in lab experiments as well as in sport settings often inferred tendencies of pairs of athletes (or two teams) towards stable in-phase and antiphase patterns of between-person synchronization. As the coupled oscillators are modeled, they attract towards each other's behaviour, in-phase and antiphase patterns reflect stable cooperative coupling situations. Interestingly, it is also possible to model *repulsive* coupling. Particularly relevant for sports, implementing *competitive* coupling between the model oscillators (i.e., one oscillator attracts while the other repels) reflects defender-attacker coupling and may yield patterns that contrast to the generally observed in- and antiphase attraction (Kelso et al., 2009; De Poel, 2016). Here, this issue is descriptively explored and illustrated this alongside data of tennis singles matches (see also McGarry and De Poel, 2016).

Methods: We analysed long (i.e., >9 successive strokes) baseline rallies taken from footage (25 frames-per-second) of men singles tennis matches at the highest competitive level (Association of Tennis Professionals tournaments). From 100 rallies for which analysable bird's-eye shot high quality footage could be attained from online sources, 31 rallies from different matches were randomly selected for digitization and analysis. For each athlete, the position of the trunk was digitized using *Tracker OSP* (open source video digitization software). The lateral displacement on the field follows a largely oscillatory path (Palut and Zanone, 2005) which allows for determining the phase angle. This was calculated using a Hilbert procedure that included half-cycle

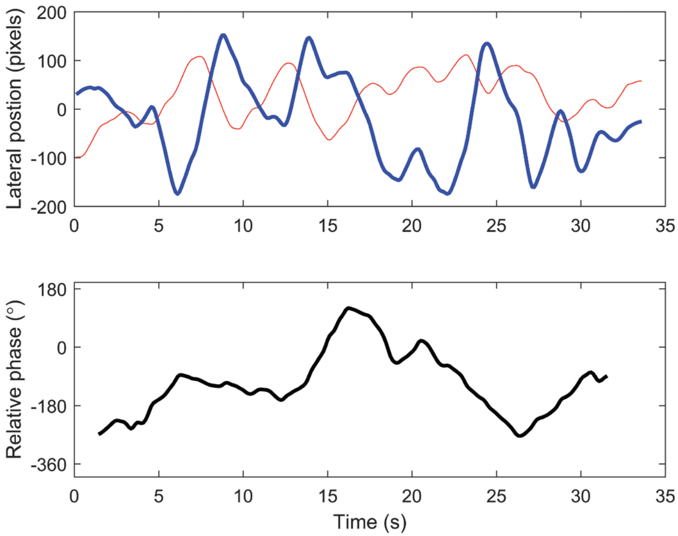


FIGURE 1: Example of data extracted from a video of a tennis rally. Top panel: digitized lateral displacements of the two tennis players. Lower panel: the associated relative phase.

normalization (this normalization was necessary to cope with artefacts due to within-trial variations in the amplitude, oscillation center, and duration of half movement cycles). Subsequently, the difference between the two phase angle series was calculated to yield the continuous relative phase between the athletes (see Figure 1).

Results and discussion: Figure 2 shows a histogram of the obtained relative phase values of all analyzed rallies. As can be seen there is a peak of higher occurrence around 0° (in-phase pattern), while there was no such peak around/close to 180° (antiphase coordination). Most notable are the clear peaks close to –90° and 90° relative phases. This corresponds with numerical simulations of competitively coupled oscillators, which showed that coordination could indeed converge toward 90° and/or –90° phase relations rather than attract to in-phase/antiphase patterns (e.g., Kelso et al., 2009). Hence, such occurrence near to 90° and –90° phase patterns likely reflect stages of truly competitive interaction. Further descriptive inspection of the data of individual rallies (see example in Figure 1) suggested that over the course of a rally, the phase relation switched between stages in which the opponents appeared to balance their interaction (i.e., relative phase around 0°, indicating in-phase pattern) and periods of clear

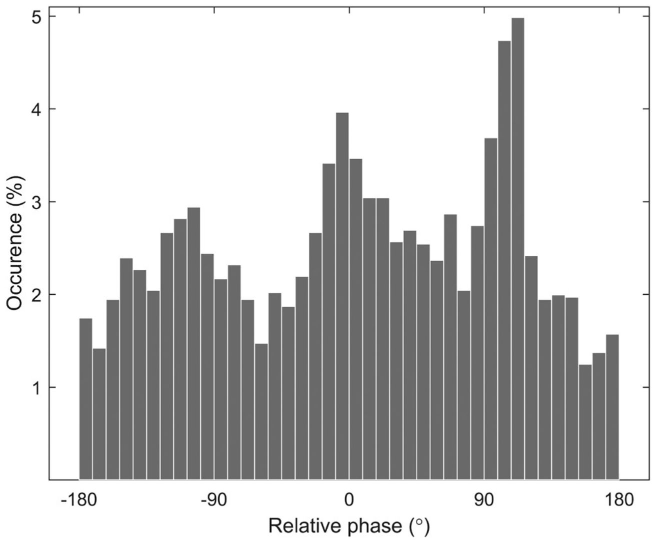


FIGURE 2: Distribution of relative phase values of all trials.

competitive movement interaction (relative phase close to 90° and –90°). This reflects that odds change back and forth within rallies: sometimes one player dominated the rally ("attacker-defender": relative phase close to 90°, see Figure 1 around the $t = 17$ s and around $t = 3$ and 27 s; note that a value of –270° is the same as 90°), whereas at other instances the other player dominated ("defender-attacker": –90°, see Figure 1 at $t = 6$–9 s and around $t = 30$ s), alternated with short periods of balance between the opponents ("defender-defender": 0°, see Figure 1 around $t = 20$ s).

Conclusion: With these tennis data it is illustrated that finding high occurrences of in-phase and/or antiphase reflect stages of balanced cooperative interaction, while 90° phase patterns likely reflect truly competitive stages. In line, it is the observation of *deviations* from balanced between-agent behaviour that most relevantly reflect the perturbations that are typical for competitive attacker–defender situations (McGarry and De Poel, 2016). However, in sports in general, during a match opponents do not aim (or are not able) to perturb each other all the time. They build in periods of balance, so as to settle for the next attempt to perturb the balanced cooperative situation. Hence, if mainly balanced patterns (i.e., in-phase) would be observed, it would primarily reflect "cooperative" situations in which opponents are "waiting for the other to make a mistake," rather than truly competitive situations with self-effectuated offensive–defensive interaction.

REFERENCES

De Poel, H. J. (2016). Anisotropy and antagonism in the coupling of two oscillators: concepts and applications for between-person coordination. *Front. Psychol.* 7:1947. doi: 10.3389/fpsyg.2016.01947 PMID:28066280

Haken, H., Kelso, J. A. S., and Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biol. Cybern.* 51, 347–356. doi: 10.1007/BF00336922 PMID:3978150

Kelso, J. A. S., de Guzman, G. C., Reveley, C., and Tognoli, E. (2009). Virtual partner interaction (VPI): exploring novel behaviors via coordination dynamics. *PLoS ONE* 4:e5749. doi: 10.1371/journal.pone.0005749 PMID:19492044

McGarry, T., and De Poel, H. J. (2016). "Interpersonal coordination in competitive sports contests," in *Interpersonal Coordination and Performance in Social Systems*, eds P. Passos, K. Davids, and J. Y. Chow (New York, NY: Routledge), 195–210.

Palut, Y., and Zanone, P. G. (2005). A dynamical analysis of tennis: concepts and data. *J. Sports Sci.* 23, 1021–1032. doi: 10.1080/02640410400021682 PMID:16194979

Visual Exploratory Behaviour in Dynamic Team Sports

Matt Dicks

Department of Sport and Exercise Science, University of Portsmouth, Portsmouth, United Kingdom
matt.dicks@port.ac.uk

Elite and developing athletes who compete in dynamic team sports such as football, basketball, and rugby are required to constantly adapt their movements relative to information from the surrounding environment, such as the positions of teammates and opponents. With every unfolding moment, teammates and opponents will move leading to changes in the environment and the invitation of a new set of possible actions. Gibson (1979) ecological approach places emphasis on the reciprocal nature of perception-action and the importance of studying the pick-up of information as an active process, which encompasses the body, head and eyes (van der Kamp and Dicks, 2017). In sport, the active search for information has been referred to as visual exploratory behavior (VEB), which has been defined as "A body and/or head movement in which the player's face is actively and temporarily directed away from the ball, seemingly with the intention of looking for teammates, opponents or other environmental objects or events, relevant to the carrying out of a subsequent action with the ball" (Jordet, 2005, p. 143). VEB is thought to support skilled performance as analysis of elite football players indicates that a higher frequency of VEB before receiving the ball is reflective of a higher forward passing accuracy (Jordet et al., 2013). The current presentation will consider how variations in practice conditions may impact upon the development of VEB in elite youth football players. First, a comparative analysis of VEB across training (i.e., small-sided and medium-sided game formats) and competitive (11-a-side) game formats will be presented (Dicks et al., in progress). Findings from this work suggest that VEBs appear to vary between the conditions of practice used in small- and medium-sided training games and those encountered by players in competition. Importantly, this indicates that the VEBs that underlie the control of skilled actions in competitive football matches may not always be optimally developed in training. Second, further to field-based training practices, the results from a season-long, off-field training intervention will be presented (Pocock et al., 2017). Specifically, this work indicated that an imagery intervention can improve VEB, with the largest performance improvements observed for central midfield players. Together, the implication of the results from these two studies will be considered relative to future research directions and applied practice.

REFERENCES

Dicks, M., Verstappen, S., Klijn, J., van der Kamp, J., and Savelsbergh, G. J. P. (in progress). Visual exploratory behaviours of elite youth football players in training and competition.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Jordet, G. (2005). Perceptual training in soccer: an imagery intervention study with elite players. *J. Appl. Sport Psychol.* 17, 140–156. doi: 10.1080/10413200590932452

Jordet, G., Bloomfield, J., and Heijmerikx, J. (2013). "The hidden foundation of field vision in English premier league (EPL) soccer players," in *Sport Analytics Conference* (Boston: Mit Sloan), 1–6.

Pocock, C., Dicks, M., Chapman, M., Barker, J., and Thelwell, R. C. (2017). Using an imagery intervention to train visual exploratory activity in elite academy football players. *J. Appl. Sport Psychol.*

van der Kamp, J., and Dicks, M. (2017). Looking further! The importance of embedding visual search in action. *Behav. Brain Sci.* e158, 45–46.

Statistical Validation of Team and Individual Performance Metrics in Sports

Jordi Duch[1,2], Luis A. N. Amaral[2,3]

[1]Departament d'Enginyeria Informàtica i Matemàtiques, Universitat Rovira i Virgili, Tarragona, Spain
[2]Northwestern Institute on Complex Systems (NICO), Northwestern University, Evanston, IL, United States
[3]Department of Chemical and Biological Engineering, Northwestern University, Evanston, IL, United States
jordi.duch@urv.cat

The amount of statistics collected in some sports has been growing exponentially due to new technologies like image processing or player position tracking. In particular, in soccer we have moved from simple player describing statistics (shots, assists, etc.) to more complex statistics that can be derived from the events that occur in a match (for instance, passing matrices that reflect the interactions between players) and, recently, to high-resolution detailed tracking data. However, the main question that arises is how to make sense of all these new huge volume of new types data, that is, what is the "real" value that a larger and more complex volume of data can add to the current knowledge of how players and teams perform? Indeed, while there are contexts in which simple measures or statistics may provide a very complete picture of an individual's performance—think of golf, baseball, or a track event—for most situations of interest, objectively quantifying individual performances or individual contributions to team performance in low-scoring sports such as soccer is far from trivial. In our previous work (Duch et al., 2010), we presented a new method of player and team performance using a network science approach by creating passing networks from the interaction between the players, and then computing the centrality of the players on the network based on the successful paths that flowed to the opponents' goal. We used bootstrap hypothesis testing to validate the metric, showing that the performance values were strongly correlated with the outcome of a match, and thus they could be used as an objective measure of performance. We also showed that the metrics were aligned with the general public consensus on the quality of team play or of individual performances. Next, we have been working to study the effect of adding more variety of data to the network analysis, combining the passing networks with positional player data or different types of ball-related events. This increases substantially the number of parameters of the system and, therefore, the complexity of the analysis, but opens the possibility to explore other types of metrics that provide information about specific aspects of the game (such as performance based on the position where a player is playing). In summary, our research is focused on proving by (i) applying the methods from network science to sports and combining them with new types of data provides an excellent opportunity to create new types of team and player performance metrics and (ii) any new type of metric based on the integration of different features has to be compared against the right reference data and validated using tools and models from computer science and statistical physics.

REFERENCE

Duch, J., Waitzman, J. S., and Nunes Amaral, L. A. (2010). Quantifying the performance of individual players in a team activity. *PLoS ONE* 5:e10937. doi: 10.1371/journal.pone.0010937 PMID:20585387

A Complex-System Approach to Sports Injury Prediction and Prevention: Looking into Muscle Injuries in Football

Sérgio T. Fonseca, Juliana M. Ocarino, Thales R. Souza,
Renan A. Resende, Natália F. Bittencourt

Graduate Program in Rehabilitation Science, Department of Physical Therapy, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil
sfonseca@ufmg.br

Prediction of complex problems, such as sports injury, involves recognizing the existence of a web of interacting determinants in their genesis. The solution rests on identifying stable profiles among the multi-level determinants that support the emergence of injuries and not on the contribution of isolated factors. We propose that sports injuries are complex emergent phenomena, produced by interactions among different units, which may produce risk profiles that are related to the emerging pattern (e.g., injury) (Bittencourt et al., 2016). Instead of only looking for the units (isolated risk factors), we should look for the existing patterns of interactions among the units. In this case, the identification of the meaningful interactions related to injury occurrence should be the cornerstone of a complex systems' approach to injury prediction and prevention. The identification of risk profiles means moving from risk factors to risk pattern recognition. Risk profiles include non-linear interactions among risk factors from different scales, such as, biomechanical, training characteristics, psychological, and physiological. To exemplify the complex nature of muscle injuries in sports, we analyzed the risk profiles, by means of classification and regression tree (CART) analysis, of 102 young football players. In agreement with the model of Mendiguchia et al. (2012), factors related to strength, flexibility, core stability, and musculoskeletal system architecture interacted in different ways to produce distinct risk or protective profiles for muscle injuries. In a second model, we examined the specific profile of hamstring injuries in 115 young football players. Again, factors related to strength, flexibility, and core stability interacted to produce risk profiles. Not surprisingly, athletes with previous muscle injuries had distinct profiles from those without previous injuries. The identification of risk profiles may inform about the probability of injury occurrence, even in the absence of a complete understanding of the complex factors that are related to the phenomenon. Thus, adopting a complex system approach may push us forward in terms of developing concepts and methods to improve sport injury prediction and prevention. In a complex model, the athlete (not the disease) should be analyzed and the research focus should be on how relationships among units (i.e., biomechanical, behavioral, physiological, and psychological) generate the emerging pattern.

REFERENCES

Bittencourt, N. F. N., Meeuwisse, W. H., Mendonça, L. D., Nettel-Aguirre, A., Ocarino, J. M., and Fonseca, S. (2016). Complex systems approach for sports injuries: moving from risk factor identification to injury pattern recognition—narrative review and new concept. *Br. J. Sports Med.* 50, 1309–1314. doi: 10.1136/bjsports-2015-095850

Mendiguchia, J., Alentorn-Geli, E., and Brughelli, M. (2012). Hamstring strain injuries: are we heading in the right direction? *Br. J. Sports Med.* 46, 81–85. doi: 10.1136/bjsm.2010.081695

The Social Synapse in Sports: Interpersonal Coordination and Nonverbal Behavior in Sports

Philip Furley

Institute for Training and Computer Science in Sports, German Sport University Cologne , Cologne, Germany
p.furley@dshs-koeln.de

Introduction: Organization in groups brings adaptive benefits to animals. However, this requires efficient communication amongst the individual group members to organize the group (Dunbar, 1993). According to "social synapse theory" (Cozolino, 2006), communication can be regarded as analogous to the neurochemical communication between synapses in the brain. The social synapse can be regarded as the space through which humans are linked together into larger units such as families, groups, and, indeed, the human race, as it conveys signals that people send out. In turn, these signals are received by our senses and sent to our brains, where they generate electro-chemical changes that again create new thoughts and behaviors that are finally transmitted back to the social synapse. Cozolino (2006), p. 24, goes on to propose that this is how humans efficiently coordinate their social lives by reliably interpreting and acting upon the signals they receive: "it appears that social communication has been chosen by natural selection to be of greater survival value than disguising our intentions and feelings, so much so that we even have ways of unintentionally "outing" ourselves to others." In this regards, Dunbar (1993) demonstrated a strong relationship between neocortex size and group size of animals. Dunbar argues that the organization in larger groups brings benefits, but requires increasing computational power (larger neocortex) for coordinating the increasing number of relationships which involves interpreting and acting upon the signals one receives (e.g., reciprocal altruism, detecting deception, and coalition formation). Hence, nonverbal expressions (synonymous to body language colloquially) are of vital importance for humans to quickly and efficiently communicate social information in complex societies (Furley and Schweizer, 2014b). Therefore, they have evolved both the ability to automatically display nonverbal behavior (NVB) and to automatically interpret and adequately respond to these NVB.

Methods and results: In a recent series of studies, the above theorizing has been transferred to the context of sports and has provided evidence that athletes, coaches, and officials are constantly sending out nonverbal signals depending on the current situation which are accurately interpreted by observers and in turn influence them. For example, research has shown that NVB of athletes occurring during the game can be interpreted as cues as to who is currently leading and who is trailing (Furley and Schweizer, 2014b), presumably because communicating status and hierarchies in confrontational encounters can be considered an adaptive mechanism for organizing group life (Furley and Schweizer, 2016; Furley et al., 2017). Further research has shown that these NVB changes occurring during sports performance affect prospective confidence levels of opponent athletes (Furley and Schweizer, 2014a). Similarly, pre-performance (Furley and Dicks, 2012) and post-performance NVB of athletes (Furley et al., 2015) have been shown to affect prospective confidence levels of both opponents and teammates, and indeed can affect behavior and performance in sports competitions (Furley et al., 2012). Further, research shows that not only does an athlete's NVB change depending on the current situation, but that this is also true for the referee (Furley and Schweizer, 2017).

Discussion and conclusion: Together these studies demonstrate that NVB reliably communicates internal states of athletes and officials and that these NVB changes have the potential to affect the outcome of sport events, for the better or the worse. Of practical importance, a large body of evidence suggests that body language (NVB) is under both conscious, deliberate control, and under unconscious, autonomous control. Contextual influences like pressure or fatigue tip the balance between unconscious and conscious control of NVB toward unconscious control (e.g., Furley and Schweizer, 2017). Hence, athletes and referees might be able to use their NVB to present themselves favorably when relaxed and rested, but might have more trouble in controlling their NVB after long durations of intense competition or in high pressure situations when thousands of people are watching and evaluating them. Hence, it is important to understand the evolutionary origins of NVB, when this evolved mechanism of displaying internal states is likely to leak information, athletes and officials would rather hide and therefore might be detrimental to sport performance, and, most importantly, how (and when) NVB can be controlled to support sport performance.

REFERENCES

Cozolino, L. (2006). *The Neuroscience of Human Relationships: Attachment and the Developing Social Brain*. New York: WW Norton & Co.

Dunbar, R. I. (1993). Coevolution of neocortical size, group size and language in humans. *Behav. Brain Sci.* 16, 681–694. doi: 10.1017/S0140525X00032325

Furley, P., and Dicks, M. (2012). "Hold your head high". The influence of emotional versus neutral nonverbal expressions of dominance and submissiveness in baseball. *Int. J. Sport Psychol.* 43, 294–311.

Furley, P., Dicks, M., Stendtke, F., and Memmert, D. (2012). "Get it out the way. The wait's killing me." Hastening and hiding during soccer penalty kicks. *Psychol. Sport Exerc.* 13, 454–465. doi: 10.1016/j.psychsport.2012.01.009

Furley, P., Moll, T., and Memmert, D. (2015). Put your hands up in the air? The interpersonal effects of pride and shame expressions on opponents and teammates. *Front. Psychol.* 6:1361. doi: 10.3389/fpsyg.2015.01361

Furley, P., Schnuerch, R., and Gibbons, H. (2017). The winner takes it all: event-relwated brain potentials reveal enhanced motivated attention toward athletes' nonverbal signals of leading. *Soc. Neurosci.* 12, 448–457. doi: 10.1080/17470919.2016.1182586

Furley, P., and Schweizer, G. (2014a). "I'm pretty sure that we will win!" The influence of score-related nonverbal behavioral changes on the confidence in winning a basketball game. *J. Sport Exerc. Psychol.* 35, 316–320. doi: 10.1123/jsep.2013-0199

Furley, P., and Schweizer, G. (2014b). The expression of victory and loss: estimating who's leading or trailing from nonverbal cues in sports. *J. Nonverbal Behav.* 38, 13–29. doi: 10.1007/s10919-013-0168-7

Furley, P., and Schweizer, G. (2016). In a flash: thin slice judgment accuracy of leading and trailing in sports. *J. Nonverbal Behav.* 40, 83–100. doi: 10.1007/s10919-015-0225-5

Furley, P., and Schweizer, G. (2017). Nonverbal communication of confidence in soccer referees: an experimental test of Darwin's leakage hypothesis. *J. Sport Exerc. Psychol.* 38, 590–597. doi: 10.1123/jsep.2016-0192

Moving from Biology to Behavior I: Leveraging Phenotypic Plasticity to Train Beyond Resiliency and toward Antifragility in Sport

Adam W. Kiefer[1,2,3]

[1]Division of Sports Medicine, Cincinnati Children's Hospital, Cincinnati, OH, United States
[2]Department of Pediatrics, College of Medicine, University of Cincinnati, Cincinnati, OH, United States
[3]Center for Cognition, Action & Perception, University of Cincinnati, Cincinnati, OH, United States
adam.kiefer@cchmc.org

The goal of most sport performance enhancement-based training programs is athletic resilience. A resilient system (e.g., athlete) is one that can cope with unforeseen challenges through the availability of adaptable reserves, and the flexibility to accommodate those challenges (Nemeth, 2008). While this is conceptually useful, resiliency is limited in that it does not allow for system growth following stressors or challenges: a resilient system adapts to stressors but then returns to its original performance level (Taleb, 2012). Recently, the concept of antifragility was introduced (Taleb, 2012) to define system capabilities beyond resiliency, and it provides a better framework for performance enhancement training. An antifragile system is one that adapts to stressors (e.g., the links among system components are reorganized) while the stressors promote a state of growth (e.g., the links between specific system components become stronger). This is a subtle, but important difference from resiliency, and one with major implications for athlete assessment and performance enhancement training. It requires a new approach for both the identification of system metaflexibility (Pincus and Metten, 2010)—i.e., metastability—across myriad stressors, and the quantification of behavioral growth. Evolutionary biology provides a theoretical framework for the development of such an approach, specifically through the well-developed principle of phenotypic plasticity (Agrawal, 2001). Phenotypic plasticity is defined as an environmentally based change in an organism's phenotype (Via et al., 1995), or observable properties (Calabrese and Mattson, 2011). For present purposes, reduced plasticity reflects a deficiency in behaviors that guarantee fitness or adaptability of biological organisms to their environment (or stressors). Importantly, differences in fitness between two organisms are not intrinsically (e.g., genetically) determined; they tend to be detectable only within a particular set of environments, or during rapid environmental transitions. When considered in the context of behavior, they are also typically modifiable (i.e., trainable). Phenotypic plasticity can, thus, be a modifiable characteristic of an organism that is contingent on a number of organism-specific factors including, but not exclusively: neural plasticity, behavior plasticity, epigenetic plasticity, and physical activity. Combined, these promote adaptability to environmental challenges (Calabrese and Mattson, 2011) and are consistent across organisms, regardless of taxonomy (Calabrese and Mattson, 2011). Therefore, phenotypic plasticity captures how adaptable an athlete is to a variety of environments and, ultimately, provides an index of antifragility. Establishing an athlete's behavioral fitness (and thus, phenotypic plasticity) requires the identification and assessment of specific behavioral variables that support an athlete's ability to modify behavior in response to dynamic environmental conditions. The first step is to identify variables that define an athlete's fitness across performance environments. Next, these fitness variables (or sets of variables) are measured at multiple time points across a variety of more challenging and complex contexts (or dosage interventions), and used to create a series of fitness scores based on one or more of the identified variables. Phenotypic plasticity is then quantified not based on one isolated score, but based on the longitudinal fitness curve created by plotting a time series of fitness scores and then computing the area under the longitudinal fitness curve. Thus, phenotypic plasticity provides a comprehensive analytic approach to investigate the athlete's adaptability to heterogeneous sport environments. It also recognizes the dynamic nature of adaptive processes and, therefore, is more sensitive in detecting the athlete's capability for behavioral transitions to more efficient performance states. Training protocols that leverage these principles necessitate a range of dynamic challenges (whether environmental or otherwise) that help build a profile of athlete fitness and, ultimately, growth in phenotypic plasticity (i.e., antifragility). Our team has developed highly advanced training methods that utilize cutting-edge virtual and augmented reality technologies, integrated with genetic fuzzy tree artificial intelligence (GFT-AI; Ernest et al., 2016), to design and deploy training environments that promote antifragility. Specifically, our innovative training system optimizes behavior modification through the assessment of specific fitness variables that inform the precise targeting of component interactions to promote efficient learning of strategies to enhance fitness and phenotypic plasticity. Importantly, the GFT-AI uses a universal approximator based on the linguistic, rule based, fuzzy inference system with rules, membership functions, and cascading architecture optimized *via* a genetic algorithm. This technique formulates a (computationally light-weight) rule structure to provide deterministic control to incredibly complex multivariate problems. Moreover, the GFT AI can perform large-scale combinatorial optimization to extract a rule that selects, based on an athlete's current status, the attentional and physical load to impart on the athlete in the training environment that will lead to the greatest improvement in fitness. Once the GFT AI is trained, the resulting general rule can be adapted in real time (≤4 ms) to direct individualized modifications to training parameters that can be implemented within and between trials. The result is custom-built, precision-based training protocols that target behavioral mechanisms that enhance metastable system dynamics and, ultimately, promotes antifragile athletic behavior.

REFERENCES

Agrawal, A. A. (2001). Phenotypic plasticity in the interactions and evolution of species. *Science* 294, 321–326. doi: 10.1126/science.1060701 PMID:11598291

Calabrese, E. J., and Mattson, M. P. (2011). Hormesis provides a generalized quantitative estimate of biological plasticity. *J. Cell Commun. Signal.* 5, 25–38. doi: 10.1007/s12079-011-0119-1 PMID:21484586

Ernest, N., Carroll, D., Schumacher, C., Clark, M., and Cohen, K. (2016). Genetic fuzzy based artificial intelligence for unmanned combat vehicle control in simulated air combat missions. *J. Def. Manag.* 6, doi: 10.4172/2167-0374.1000144

Nemeth, C. P. (2008). "Resilience engineering: The birth of a notion," in *Resilience Engineering Perspectives*, Vol. 1, eds E. Hollnagel, C. P. Nemeth, and S. Dekker (Burlington, VT: Ashgate Publishing Ltd), 5–6.

Pincus, D., and Metten, A. (2010). Nonlinear dynamics in biopsychosocial resilience. *Nonlinear Dynamics Psychol. Life Sci.* 14, 353–380. PMID:20887686

Taleb, N. (2012). *Antifragile: Things That Gain from Disorder (Incerto)*. New York: Random House.

Via, S., Gomulkiewicz, R., De Jong, G., Scheiner, S. M., Schlichting, C. D., and Van Tienderen, P. H. (1995). Adaptive phenotypic plasticity: consesus and controversy. *Trends Ecol. Evol.* 10, 212–217. doi: 10.1016/S0169-5347(00)89061-8

Coherent Teams: New Techniques and Technologies for Improving Team Dynamics and Performance

Rollin McCraty

HeartMath Institute, Boulder Creek, California, United States
rollin@heartmath.org

It has become abundantly apparent that biological processes vary in complex and non-linear ways, even during so called “steady-state” conditions. It is now understood that healthy, optimal function is a result of continuous, dynamic, bi-directional interactions among multiple neural, hormonal, and mechanical control systems at both local and central levels. These regulatory systems are never truly at rest and are certainly never static. For example, we now know that the normal resting rhythm of the heart is highly variable rather than being monotonously regular, which was the widespread notion for many years (McCraty and Shaffer, 2015). In complex globally coherent systems, such as human beings, there is an incredible amount of activity at every level of magnification or scale that spans more than two thirds of the 73 known octaves of the electromagnetic spectrum. In living systems, there are micro-level systems, molecular machines, protons and electrons, organs and glands each functioning autonomously, doing very different things at different rates, yet all working together in a complex coherently coordinated and synchronized manner (Ho, 2005). At another leave of scale, humans are organized in complex social networks which can be either discordant, optimal. Team coherence, relates to the network of relationships, which exists among individuals who share common interests and objectives. Team coherence is reflected in a stable, harmonious alignment of relationships, which allows for the efficient flow and utilization of energy and communication required for optimal collective cohesion and action. Anyone who has experienced an exceptional sports team recognizes that something extraordinary can take place when team members surpass their normal performance. At those times, it appears that the players are in-sync and communicating on an unseen level. There are several lines of research suggesting that an energetic field connects individual group members, which simultaneously distributes information between the group members. This requires that team members are attuned and are emotionally connected with each other, and that the group’s energy is globally organized and regulated by the group as a whole. In a coherent team, there is freedom for the individual members to each to do their parts while maintaining cohesion and resonance within the group’s intents and goals so team members and the team can thrive. There are many types of coherence, however, the term always refers to connections between various parts of a system, and implies a harmonious relationship between the parts of a larger system. In the context of team coherence, it relates to the harmonious alignment between team members, in which a network of relationships exists among individuals who share common interests and objectives. A high degree of team coherence is reflected by stable and harmonious relationships, which allows for the efficient flow and utilization of energy and communication required for optimal collective cohesion and action. Team coherence requires that group members are attuned and are emotionally connected with each other, and that the group's energy is organized and regulated by the group as a whole. A number of studies have explored various types of synchronization which show that feelings of trust and cooperation, as well as increased prosocial behaviors is strongly facilitated by the establishment of synchronization of various physiological rhythms among team members. In order for the physiological activity of separate individuals to synchronize, a signal of some type must convey information between them. In addition to research on the role of visual, auditory, and tactile signals in mediating various types of synchronization, there are several lines of research suggesting that an energetic field connects individual group members, which simultaneously and nonlocally distributes information between the group members. Until now, the ability to study synchronization in teams has been limited. We have developed a new platform that utilizes heart rate variability monitoring in team contexts, combined with self-regulation techniques that shift the individuals into an optimal physiological state that allows increased physiological synchronization between team members to naturally emerge. Research has also found that most groups have a global organization, structured as a coherent network of emotional connections that form a single multi-level hierarchy in which the relationship between the number and structure of reciprocated positive emotional bonds and control relationships that can predict group stability and performance two years later (Bradley and Pribram, 1998). The theory that best fits the data from these studies is one built on field theory and nonlocal information exchange where information about the structure of the entire group is simultaneously distributed to all of the group members, a "social hologram." We have suggested that biologically generated magnetic fields, may act as a carrier wave for transferring information between individuals and group members (McCraty and Deyhle, 2015). There are practical steps and practices that can help increase and stabilize team coherence and resilience in, teams. The team coherence program focus on practical skills that increase self-regulatory capacity and personal coherence as this creates the foundation for team coherence.

REFERENCES

Bradley, R. T., and Pribram, K. H. (1998). Communication and stability in social collectives. *J. Soc. Evolution. Syst.* 21, 29–80. doi: 10.1016/S1061-7361(99)80005-8

Ho, M.-W. (2005). *The Rainbow and the Worm: The Physics of Organisms*. Singapore: World Scientific Publishing Co.

McCraty, R., and Deyhle, A. (2015). "The global coherence initiative: investigating the dynamic relationship between people and earth's energetic systems," in *Bioelectromagnetic and Subtle Energy Medicine*, 2nd Edn, ed. P. J. Rosch (Boca Raton, FL: CRC Press), 411–426.

McCraty, R., and Shaffer, F. (2015). Heart rate variability: new perspectives on physiological mechanisms, assessment of self-regulatory capacity, and health risk. *Glob. Adv. Health Med.* 4, 46–61. doi: 10.7453/gahmj.2014.073 PMID:25694852

Recent Trends in Match Analysis with Positional Data

Daniel Memmert

Institute of Training and Computer Science in Sport, German Sport University Cologne, Cologne, Germany
memmert@dshs-koeln.de

State of the art of research as well as public interest is calling for a detailed and objective scientific analysis of soccer matches (Rein and Memmert, 2016). The main aim of this talk is the quick and valid identification of key performance indicator (KPI) in men's professional soccer (Memmert et al., 2017). Here, some novel objective analysis tools come into play, e.g., neural networks (for an overview, Perl and Memmert, 2012), which can identify tactical pattern based on position data. In the last 2 years, we developed a hierarchy of several artificial neural networks that allow for a rapid identification and classification of complex tactical patterns in soccer (Memmert and Perl, 2009a,b). Based on the position data of 22 players and the ball, we can find the characteristic movement and interaction patterns of each team and characteristic interaction patterns between both teams (Grunz et al., 2012). Characteristic means of several slightly distinct realizations of movements on the soccer field are summarized in only one movement pattern. If a team attacks always in a similar fashion, the algorithm will reduce these attacks to a pattern. For example, if a team attacks always on the left side, we obtain movement patterns describing the movements on the left wing. That means, the frequency of attacks on the wings/via the center, or the number of attacks that were conducted by means of short/long passes (always including the respective probabilities of success). Such statistics could lead to more elaborate findings than the average information that are usually discussed (e.g., percentage of ball possession), but still collected manually (Memmert and Raabe, 2017). Our complex characteristic patterns can be calculated automatically in a very short time (less than 3 s). In an additional step, this pattern can be visualized on a drawn soccer field and be presented to coaches (Perl et al., 2013).

REFERENCES

Grunz, A., Memmert, D., and Perl, J. (2012). Tactical pattern recognition in soccer games by means of special self-organizing maps. *Hum. Mov. Sci.* 31, 334–343. doi: 10.1016/j.humov.2011.02.008 PMID:21669468

Memmert, D., Lemmink, K. A. P. M., and Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Med.* 47, 1. doi: 10.1007/s40279-016-0562-5 PMID:27251334

Memmert, D., and Perl, J. (2009a). Analysis and simulation of creativity learning by means of artificial neural networks. *Hum. Mov. Sci.* 28, 263–282. doi: 10.1016/j.humov.2008.07.006

Memmert, D., and Perl, J. (2009b). Game creativity analysis by means of neural networks. *J. Sport Sci.* 27, 139–149. doi: 10.1080/02640410802442007

Memmert, D., and Raabe, D. (2017). *Revolution in Professional Soccer: With Big Data towards Match Analysis 4.0*. Berlin: Springer-Verlag.

Perl, J., Grunz, A., and Memmert, D. (2013). Tactics in soccer: an advanced approach. *Int. J. Comput. Sci. Sport* 12, 33–44.

Perl, J., and Memmert, D. (2012). Special issue: network approaches in complex environments. *Hum. Mov. Sci.* 31, 267–270. doi: 10.1016/j.humov.2012.04.001

Rein, R., and Memmert, D. (2016). Big data and tactical analysis in elite soccer: future challenges and opportunities for sports science. *Springerplus* 5, 1410. doi: 10.1186/s40064-016-3108-2 PMID:27610328

An Exploratory Approach to Capture Interpersonal Synergies between Defenders in Football

J. Milho[1,2], P. Passos[3]

[1]Instituto Superior de Engenharia de Lisboa (ISEL), Instituto Politécnico de Lisboa, Lisboa, Portugal
[2]IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal
[3]CIPER, Laboratory of Motor Behavior, Faculdade de Motricidade Humana, Universidade de Lisboa, Lisboa, Portugal
joao.milho@dem.isel.ipl.pt

Introduction: Collective behaviors in football may result from players forming interpersonal synergies that contribute to performance goals. Due to the huge number of variables that continuously constrain players' behavior during a game, the way that these synergies are formed remain unclear. In team sports such as football, a common effective defensive tactical strategy is one in that defending players "fill" the space between themselves, disturbing the attackers intentions to get closer to the goal and score. To assemble such situations, we hypothesized that the defenders create a functional synergy, which occurs when components of a system behave as a whole contributing to the development of a specific task (Kelso, 2009). Supported on a previous research in Rugby Union (Passos et al., 2017), we postulate that synergies are—mechanisms that substantiate interpersonal coordination in team sports of Football. It is relevant to state that a general feature of coordination is the mutual dependency among system components (e.g., defenders), which led them to behave (e.g., play) as a whole (Kugler and Turvey, 1987; Kelso, 2009). The creation of a synergy is grounded on a complementarity between variability and stability, which means that some defending player's (as components of a system) must vary the manner they interact to stabilize specific performance variables (Black et al., 2007; Passos et al., 2017). On this exploratory study, our aim was to quantify interpersonal synergies in team sport of football, in particular, to quantify dyadic interpersonal synergies between the four field defenders that formed the defensive squad of a football team. We hypothesized that neighboring defending players adjust their relative positions to stabilize an interpersonal distance and as such create interpersonal synergies.

Methods: The data used in this study was captured during an official football match from the Dutch first league and the company who collected the data kindly provided it. To measure players' relative co-positioning during performance in a football match, bi-dimensional coordinates x and y of each player in the playing field were recorded at 25 fps, using an automatic video tracking system. Similar to recent research in Rugby Union (Passos et al., 2017), we used the uncontrolled manifold hypothesis (UCM) to identify interpersonal synergies that are formed between pairs of defenders during the attacking phases of the opposing team. The variable which best describes how defending player's "fill" the gap between them is the players' transversal displacements (i.e., on the *y* axis along the field width). Thus on this first stage, hypothetical synergies were calculated using the players' transversal displacement. The interpersonal distance for each dyad of players was used as a performance variable and players distance to the field sideline (characterizing players' transversal displacement) was used as task relevant element. We analyzed the existence of interpersonal synergies between the three dyads formed by four neighboring defending players on six attacking situations, which provide 18 hypothetical interpersonal synergies (Figure 1).

Results: For the hypothetical 18 interpersonal synergies, only three of them revealed no synergy formation (i.e., UCM values lower than 1). The remaining 15 revealed the existence of interpersonal synergies, which suggests that defenders adjustments in the transversal plane of motion (captured by the changes on the players' distance to the sideline) contribute to stabilize the player's interpersonal distances (Table 1). It should be emphasized the different strength of coupling between the three dyads. The UCM values present a large range between a minimum value of 1.1 and the maximum of 45.1. On average dyad 1 display the lowest UCM values whereas dyad 2 display the highest UCM values but also with the highest standard deviation.

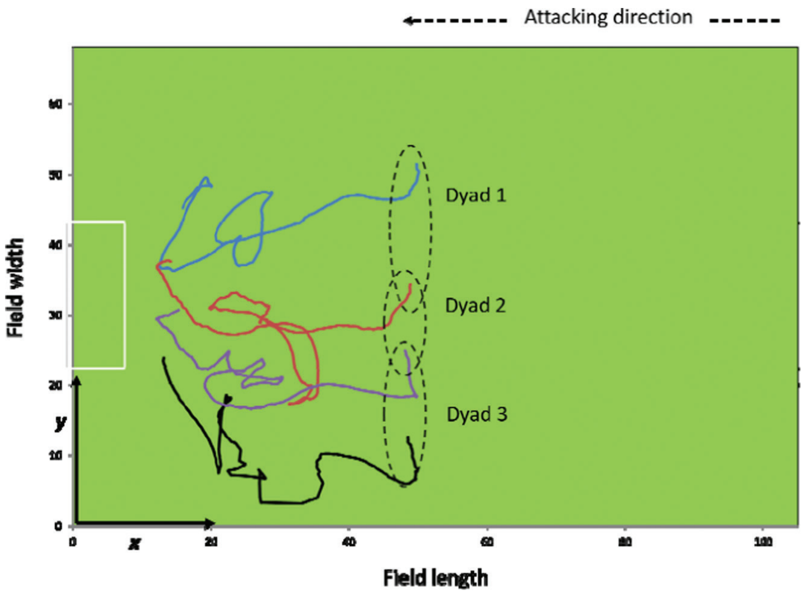


FIGURE 1: Defending players' dyads (filled lines represent an example of the four defenders trajectories during an attacking phase of the opposing team).

TABLE 1: Data and descriptive statistics of the UCM values of the three defending dyads during six organized attacking sub-phases of the opposing team.

Play	UCM (dyad 1)	UCM (dyad 2)	UCM (dyad 3)
1	2.4	10.8	13.8
2	6.9	45.1	9.1
3	4.1	0.9	1.1
4	0.9	15.0	22.5
5	3.7	1.2	0.5
6	21.1	7.8	15.7
Average	6.5	13.5	10.4
Stdev	7.4	16.4	8.6

Discussion and conclusion: Uncontrolled Manifold Hypothesis analysis shows considerable promise as a performance analysis tool in football to discriminate between skilled sub-groups of players, and identify potential advantageous situations for the defensive squad. For instance, on this exploratory study it was possible to identify that dyad 1 has the weakest synergies whereas dyad 2 formed the strongest interpersonal synergies (Black et al., 2007). How the formed synergies relate with players functional behavior is an issue for further research. The different strengths of the formed synergies are due to the specificity of each situation characterized by the different constraints (e.g., ball displacement; opposing players' interpersonal distance; proximity to ball carrier). These task constraints influences how each defending player adjust to the behavior of his closest neighbor, which consequently influences the strength of the formed synergies or even disturb the formation of potential interpersonal synergies.

Acknowledgment

The players football data was kindly provided by STATS LLC.

REFERENCES

Black, D. P., Riley, M. A., and McCord, C. K. (2007). Synergies in intra- and interpersonal interlimb rhythmic coordination. *Motor Control* 11, 348–373. doi: 10.1123/mcj.11.4.348 PMID:18042965

Kelso, J. A. (2009). "Synergies: atoms of brain and behavior," in *A Multidisciplinary Approach to Motor Control*, Vol. 629, ed. D. Sternad (Heidelberg: Springer), 83–91.

Kugler, P., and Turvey, M. T. (1987). *Information, Natural Law, and the Self-Assembly of Rhythmic Movement*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Passos, P., Milho, J., and Button, C. (2017). Quantifying synergies in two versus one situations in team sports: an example from Rugby Union. *Behav. Res. Method*. doi: 10.3758/s13428-017-0889-3

Analysis of Dynamic Processes in Football

Jürgen Perl

University of Mainz, Mainz, Germany
juergen.perl@t-online.de

Over decades, game analysis in sports was a thrilling, but academic job. The reason was the lack of data, reducing game analysis to developing theoretical models. Since about 10 years, an increasing offer of position data of high quality enables for getting those theoretical approaches to practical work. One particular example is the neural network approach. Self-organizing neural networks (SOM) can transform complex structures or dynamics into comparably simple patterns (Perl and Memmert, 2012). Regarding a game like football such techniques allow drawing a bow from position-oriented situations and events like ball control and passes over dynamic processes like ball recovery or attacks to tactical patterns like dynamic player formations and their interactions (Grunz et al., 2012). Against this background even comparably simple performance indicators like ball control can reach a new level of information and importance just by imbedding them into the context of dynamic processes and tactical patterns. During the past, about 10 years, the football analysis system SOCCER has been developed in cooperation with the German University of Cologne (Memmert and Perl, 2009a,b), which provides numerous components and analysis tools ranging from statistical analyses of event distributions up to network-based analyses of complex tactical processes. In a current pilot-study (Perl and Memmert, 2017), it is demonstrated exemplarily how SOCCER is able to combine two comparably simple KPIs, namely ball control and space control, to a process-oriented KPI that is able to characterize the offensive success of a team. The way how it is done is briefly sketched by the following example. Figure 1 shows the ball control events of team A in the 30-m area in front of the goal of team B in a 300-s interval between 23:42 and 38:42 min as violet lines, the corresponding space control events as gray lines, and the corresponding space control rates as green profile. All following explanations refer to the 30-m area and this particular time interval. The introduced indicators are defined as follows, where "LB" means a lower bound of importance.

Ball Control Events

$$\text{BCE}\ (t) = \text{if the team controls the ball at time } t \text{ then 1 else 0} \tag{1a}$$

Space Control Events

$$\text{SCE}\ (t) = \text{if \% -rate of controlled space at } t \text{ is} > \text{LB then 1 else 0} \tag{1b}$$

Space Control Events

$$\text{SCR}(t) = \text{if } \% - \text{rate of controlled space at } t \text{ is} > \text{LB then } \% - \text{rate of controlled space at } t \text{ else } 0 \tag{1c}$$

Of course, each of these indicators alone does not make a lot of sense. Controlling space without controlling the ball and vice versa is not very likely to generate dangerous situations. If, however, ball control meets space control in the critical area, this normally indicates a dangerous situation for the opponent. Therefore not the number of events, but the correlation between them should play a role for indicating success of attacks. A basic model from economy containing the term "success" is given by

$$\text{Success} = \text{Efficiency} \times \text{Effort}. \tag{2}$$

Projected to the situation of soccer, the terms Effort, Efficiency, and Success can be defined as follows, regarding to an interval of length IL, ending in second t0:

Under the aspect of offensive success, *Effort* means the number of all actions in order to generate dangerous situations in the opponent's critical area over a selected time interval (violet and gray vertical lines in Figure 1)

$$\text{Effort}(\text{IL}, t0) = \text{sum}(\text{BCE}(t) \oplus \text{SCE}(t)),\ t = t0 - \text{IL} + 1, \ldots, t0. \tag{3}$$

To avoid double counting active t-points, instead of "+" the operator "⊕" is used with a meaning similar to the logic "or," i.e., "1+1=1." In the example of Figure 1, the effort value sums up to 168. It was pointed out that neither ball control nor space control alone are normally successful in generating dangerous situations. Instead, a coincidence of ball and space control seems to be necessary. *Efficiency* is therefore defined as a correlation between ball control events BCE(t) and space control rates SCR(rates), which leads to

$$\text{Efficiency}(\text{IL}, t0) = \text{corr}(\text{BCE}(t), \text{SCR}(t), t = t0 - \text{IL} + 1, \ldots, t0. \tag{4}$$

The gray profile in Figure 2 presents the attacking efficiency as the correlation between ball control events and space control rates. Each point of this gray profile means the correlation value regarding the 300 sec-interval left from the selected t0. In the selected interval, this correlation has a value of 0.75. *Offensive Success* can now be deduced from Eqs 3 and 4, where, in order to get comparable results independent of the length of the interval, the value of OS is normalized by the length of the interval.

$$\text{OS}(\text{IL}, t0) = \text{Efficiency}(\text{IL}, t0) \times \text{Effort}(\text{IL}, t0)/\text{IL}. \tag{5}$$

The red profile in Figure 2 presents the values of offensive success depending on the selected t0. In the selected interval, the offensive success has a value of $0.42 = 0.75 \times 168/300$. The presented approach demonstrates how a KPI can be deduced from simple modeling assumptions without neglecting the complex playing dynamics. In particular, the orientation to intervals opens access to a better understanding of offensive dynamics and offensive success.

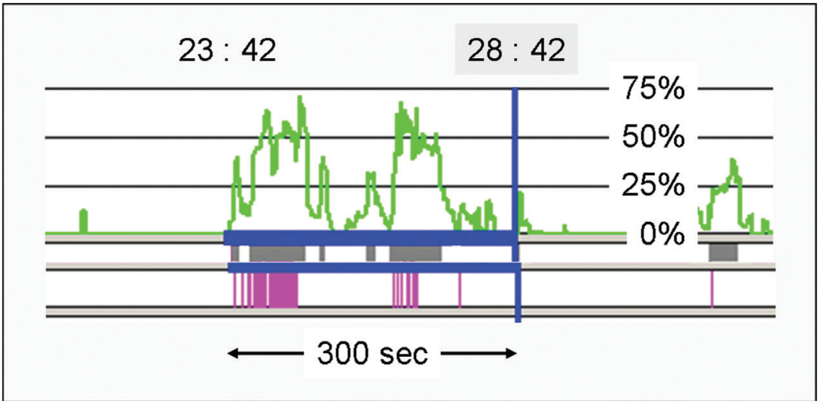


FIGURE 1: Ball control events (vertical violet lines), space control events (vertical gray lines) and space control rates (green profile).

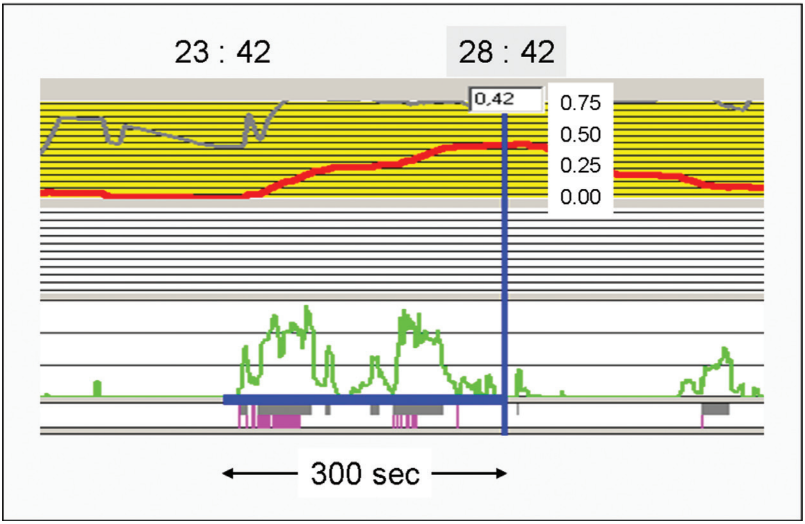


FIGURE 2: Gray profile and red profile representing interval-specific control correlation and offensive success values, respectively.

REFERENCES

Grunz, A., Memmert, D., and Perl, J. (2012). Tactical pattern recognition in soccer games by means of special self-organizing maps. *Hum. Mov. Sci.* 31, 334–343. doi: 10.1016/j.humov.2011.02.008 PMID:21669468

Memmert, D., and Perl, J. (2009a). Analysis and simulation of creativity learning by means of artificial neural networks. *Hum. Mov. Sci.* 28, 263–282. doi: 10.1016/j.humov.2008.07.006

Memmert, D., and Perl, J. (2009b). Game creativity analysis by means of neural networks. *J. Sport Sci.* 27, 139–149. doi: 10.1080/02640410802442007

Perl, J., and Memmert, D. (2012). Special issue: network approaches in complex environments. *Hum. Mov. Sci.* 31, 267–270. doi: 10.1016/j.humov.2012.04.001

Perl, J., and Memmert, D. (2017). A Pilot study on offensive success in soccer based on space and ball control – key performance indicators and key to understand game dynamics. *Int. J. Comput. Sci. Sport* 16, 65–75. doi: 10.1515/ijcss-2017-0005

Modeling Team Games As a Dynamic Systems—Status Quo and Future Directions

Robert Rein

Institute of Training and Computer Science in Sports, German Sport University Cologne, Cologne, Germany
r.rein@dshs-koeln.de

During the last 2 years, the interest in data-driven analyses of team games has shown a tremendous increase in terms of publications. Using notational analysis approaches, several insights have been made regarding the structure of the game starting with the seminal investigations by Reep and Benjamin (1968). However, more recently, criticism has been raised regarding the validity and in particular the relevance with respect of the relevance of many findings (Mackenzie and Cushion, 2013). One point which seems particular striking is the lack of a proper theoretical framework and/or model describing team games (Garganta, 2009; Mackenzie and Cushion, 2013). One model which has been repeatedly suggested in this regard is based on a Dynamic system theoretical framework (Reed and Hughes, 2006; Garganta, 2009; Duarte et al., 2012). Accordingly, several studies have used terminology from dynamics systems theory to analyze facets of team game performance (Duarte et al., 2012). However, although modelling team games as dynamic systems intuitively seem to have intuitive merit, it appears that the underlying theoretical development is somewhat loosely used. For example, one of the basic premises of dynamic systems modelling approach relies on a definition of a phase space. The phase space constitutes a key concept which describes a theoretical abstractions describing mathematically a space, where the system resides in and which enables to capture the dynamics of the system in a meaningful manner. Current suggestions regarding appropriate phase space variables in team game vary widely (Grehaigne et al., 1997; Duarte et al., 2012; Gréhaigne and Godbout, 2014). In this regard, a common approach for example is to use some variations of the relative phase between players as a measure to capture coordination phenomena between players (Sampaio and Macas, 2012). Relative phase theoretical approaches are grounded in models of physical dynamical systems. Here in particular, oscillator type components typically represent the system's building blocks or basic entities (Pikovsky et al., 2003). In this instance, modelling efforts using relative phase are immediately appropriate as the oscillatory behavior can be sufficiently described using a phase space consisting of the angle position and the angular velocity. However, how this concept can be mapped onto players on the pitch seems somewhat elusive. Accordingly, the question of whether an oscillator assumption is justified to model team games is an open question at present. Consequently, modeling efforts of soccer games as a dynamic system which go beyond a purely phenomenological description are therefore not available at present. This lack of a higher-order description about soccer team dynamics also seems to play into the problem of research findings readily transferring into practice (Nevill et al., 2008).

REFERENCES

Duarte, R., Araujo, D., Correia, V., and Davids, K. (2012). Sports teams as superorganisms: implications of sociobiological models of behaviour for research and practice in team sports performance analysis. *Sports Med.* 42, 633–642. doi: 10.2165/11632450-000000000-00000 PMID:22715927

Garganta, J. (2009). Trends of tactical performance analysis in team sports: bridging the gap between research, training and competition. *Port. J. Sports Sci.* 9, 81–89.

Grehaigne, J.-F., Bouthier, D., and David, B. (1997). Dynamic-system analysis of opponent relationships in collective actions in soccer. *J. Sports Sci.* 15, 137–149. doi: 10.1080/026404197367416 PMID:9258844

Gréhaigne, J.-F., and Godbout, P. (2014). Dynamic systems theory and team sport coaching. *Quest* 66, 96–116. doi: 10.1080/00336297.2013.814577

Mackenzie, R., and Cushion, C. (2013). Performance analysis in football: a critical review and implications for future research. *J. Sports Sci.* 31, 639–676. doi: 10.1080/02640414.2012.746720 PMID:23249092

Nevill, A., Atkinson, G., and Hughes, M. D. (2008). Twenty-five years of sport performance research in the Journal of Sports Sciences. *J. Sports Sci.* 26, 413–426. doi: 10.1080/02640410701714589 PMID:18228169

Pikovsky, A., Rosenblum, M., and Kurths, J. (2003). *Synchronization: A Universal Concept in Nonlinear Sciences.* Cambridge: Cambridge University Press.

Reed, D., and Hughes, M. D. (2006). An exploration of team sport as a dynamical system. *Int. J. Perform. Anal. Sport* 6, 114–125.

Reep, C., and Benjamin, B. (1968). Skill and chance in association football. *J. R. Stat. Soc. A* 131, 581–585. doi: 10.2307/2343726

Sampaio, J., and Macas, V. (2012). Measuring tactical behaviour in football. *Int. J. Sports Med.* 33, 395–401. doi: 10.1055/s-0031-1301320 PMID:22377947

A Rule Induction Framework to Measure the Representativeness of Skill Practice and Performance

Sam Robertson[1], Damian Farrow[1,2]

[1]Institute of Sport, Exercise and Active Living (ISEAL), Victoria University, Melbourne, Australia
[2]Australian Institute of Sport, Canberra, Australia
Sam.Robertson@vu.edu.au

Objectives: Improving the understanding of the conditions experienced by performers in sports training and competition represents an ongoing challenge for researchers and coaches alike. Brunswik (1956, p. 39) proposed that the "proper sampling of situations and problems may in the end be more important than proper sampling of subjects." Building on these early writings, representative learning design (RLD) was proposed as a framework to assess the extent to which practice is representative of a competitive situation of interest (Pinder et al., 2011). In particular, RLD emphasizes the ability of performers to couple the acquisition and use of specific information sources from the environment to afford action. Consequently, the importance of determining and representing the key specifying information in a practice setting is critical. However, there has been relatively little progress in the methods used to determine the representativeness of a given practice or skill testing situation. Improvements to the measurement and analysis of RLD would allow for the further refinement of training environments that specifically replicate competition conditions (Pinder et al., 2011). This would also provide necessary context with respect to the evaluation of athlete performance (Farrow and Robertson, 2017). Application of machine learning approaches, such as rule induction present a method of uncovering the manner in which the abovementioned specifying information interacts with the performer in skill practice and performance, thus offering insights that have been previously unobservable. The aim of this study was to develop a rule induction-based framework to measure the representativeness of skill behavior in practice and competition. An example of the framework is provided from the skill of kicking in elite Australian Rules football.

Methods: A total of 9,005 kicks were collected from 46 matches performed in the 2015 Australian Football League (AFL) season. In Australian football, the kick constitutes the primary method of moving the ball around the field. Each kick was assessed through either live or video observation. To provide a measure of representativeness, seven specifying variables consisting of 23 sub-categories were considered (see below).

Time in possession	Kick source	Kick distance	Kick pressure
<2 s	Free kick	0–40 m	None
2–4 s	Mark	40 m +	Chase
4–6 s	Handball receive		Frontal
6+ s	Stoppage		Tackle
	Ground ball		

Kick target	Kick ground location	Speed at kick	
Open	Forward 50 m arc	Stationary	
Covered	Forward midfield	Run	
	Defensive midfield		
	Defensive 50 m arc		

To model the interaction between the abovementioned specifying variables for each kick, a rule induction (the *Apriori* algorithm) analysis approach was implemented (Agrawal and Srikant, 1994). Specifically:

Let X be a set of specifiuying variables, $X \Rightarrow Y$ the association rule, and T a set of kicks in a given database

Therefore, if an event (kick) included in the database fulfils the conditions of X, then it also fulfils the conditions of Y. The output of this algorithm can be altered by adjusting a range of factors relating to the interestingness and prevalence of rules in a database. The most common two parameters used in generating such relevant rules from a set of all possible rules are *Support* and *Confidence*. Support refers to the frequency in which a particular specifying variable appears in the dataset and is defined as:

$$support(X) = \frac{\left|\{t \in T; X \subseteq t\}\right|}{|T|}$$

Confidence relates to how often an outputted rule has been found to be true in a given dataset and can be expressed as:

$$confidence(X \Rightarrow Y) = supp(X \cup Y) / supp(X)$$

Results: Two models combining different levels of minimum support and confidence were developed. The first was designed to require a minimum support of 0.33 (2,972 kicks) and a minimum confidence of 0.1. This resulted in the generation of only three rules, which are displayed below (kick count in parentheses):

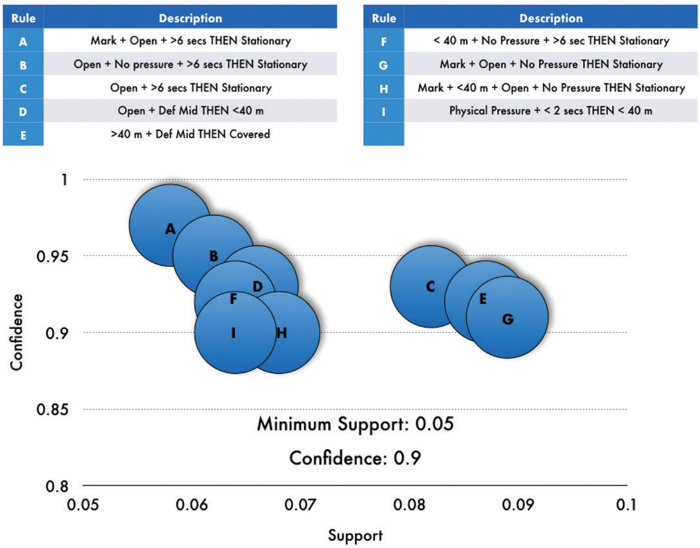


FIGURE 1: Scatterplot displaying the nine rules generated from the Low Support, High Confidence model.

	Rule	Support	Confidence
1	Stationary (5,294) ⇒ <40 m (3,626)	40%	68%
2	Stationary (5,294) ⇒ Covered (3,154)	35%	60%
3	<40 m (5,712) ⇒ Covered (3,318)	37%	58%

Due to the high minimum support requirement, the rules outputted consisted of modeling interactions between only two specifying variables. Thus, although the rules displayed a high frequency in the database, they only describe the typical conditions experienced while performing a kick in a broad manner. The confidence in being able to predict one specifying variable in the presence of another is also only slightly better than chance (50%). The second model required a comparatively lower minimum support of 0.05 (450 kicks) and a higher minimum confidence of 0.9. The nine rules generated can be viewed in Figure 1 as a scatter plot. The rules shown in the top right corner of the plot are both more predictable, as well as more prevalent in the dataset. Although these rules are also less generalizable to new scenarios than in the first model, they are able to define the kick in a more sophisticated manner than the previous iteration by including four or five specifying variables.

Conclusion: Application of rule induction to the measurement of representativeness allows for patterns and interactions between specifying variables in skilled practice and performance settings to be uncovered and emphasized in a manner not previously available. By adjusting the minimum support and confidence values associated with these rules, the emphasis between generalizability and specificity can be concomitantly altered depending on the levels of detail required by the end user.

REFERENCES

Agrawal, R., and Srikant, R. (1994). "Fast algorithms for mining association rules," in *Proceedings of 20th International Conference of Very Large Databases, VLDB*, Vol. 1215, San Francisco, 487–499.

Brunswik, E. (1956). *Perception and the Representative Design of Psychological Experiments*. Berkeley, CA: University of California Press.

Farrow, D., and Robertson, S. (2017). Development of a skill acquisition periodisation framework for high-performance sport. *Sports Med.* 47, 1043–1054. doi: 10.1007/s40279-016-0646-2 PMID:27873190

Pinder, R. A., Davids, K., Renshaw, I., and Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *J. Sport Exerc. Psycho.* 33, 146–155. doi: 10.1123/jsep.33.1.146 PMID:21451175

Neurobiological Degeneracy: A Key Property for Functional Adaptations of Perception and Action to Constraints

Ludovic Seifert

Normandie University, UNIROUEN, CETAPS, Rouen, France
ludovic.seifert@univ-rouen.fr

Research in the field of motor control, following ecological dynamics framework has seen the development of new insights about the functional role of movement variability as an emergent response to interacting constraints in order to satisfy task goals (Davids et al., 2003). Based on performer-environment circular coupling, we explain how complex neurobiological systems can exhibit perceptual-motor adaptability, which overcome the paradox between stability and flexibility. Our hypothesis is that skilled behaviour not only demonstrates stability and flexibility, but also exhibits a subtle blend between stability and flexibility, reflecting a higher level property called “adaptability” (Seifert et al., 2016). Adaptability means adapted and adaptive qualities: adapted behaviour to a given set of constraints reveals stability against perturbations, while adaptive behaviour reflects flexibility to guarantee functional solutions to constraints that dynamically interact. We clarify how this adaptability can emerge from degeneracy and pluripotentiality properties (Noppeney et al., 2004; Mason, 2014). Degeneracy refers to the ability of elements that are structurally different to perform the same function or yield the same output (Edelman and Gally, 2001; Price and Friston, 2002). The key difference is how degeneracy is described as many structures-one function relationship while pluripotentiality is referred to a one structure-many functions relationship (Noppeney et al., 2004; Whitacre, 2010). This conceptualization of degeneracy emphasizes the importance of variability in achieving performance outcomes, implying a shift away from a normative categorization of an action as, for example, a “classic technique” in sport. In human movement systems, degeneracy practically infers how the same function can be achieved by two different biomechanical architectures, each involving different joints (i.e., many structures-to-one function), as well as by several joints working together (i.e., one structure-to-many functions), while leaving some joints free for future involvement (Seifert et al., 2016). It signifies that, in sport performance, although basic movement patterns need to be acquired by developing athletes, there exists no ideal movement template towards which all learners should aspire, since relatively unique functional movement solutions emerge from the interaction of key constraints (Davids et al., 2003). In seeking to become expert, athletes can exploit inherent system degeneracy to achieve their task objectives by strategically stabilising or de-stabilising their coupling of movement and information. It provides adaptive flexibility in coping with performance perturbations to movement coordination and control and maintaining system stability. For instance, if the task goal for an icefall climber is to anchor his/her ice axes in the ice surface, he/she can demonstrate functional stability such as "swinging" ice axes against the icefall to create specific anchorages. But if the icefall already provides support in the form of existing holes in its structure, an ice climber can also demonstrate functional flexibility by "hooking" the blade of the ice axes into these existing holes in the icefall, affording support on the ice surface (Seifert et al., 2014b). Such adapted behaviours are characterized by stable and reproducible movement patterns. These patterns are stable in the sense that functional forms of movement are consistent over time, resistant to perturbations and reproducible in a relatively similar pattern may emerge under different task and environmental constraints. Although movement coordination patterns can reveal regularities and similarities within their structural components, an individual is not fixed into a rigidly stable solution, but can adapt movement coordination patterns in a functional way. Adaptive behaviours, in which system degeneracy is exploited, signify that perceptual motor systems are stable when needed, and flexible when relevant. Thus, on the one hand, the presence of degeneracy in a neurobiological system supports its stability in the sense that it increases its complexity and the robustness of its functions against perturbation. On the other hand, more than simply ensuring stability against perturbations and adaptations to a dynamical performance environment, the degenerate architecture of neurobiological systems can exhibit creativity, leading to the hypothesis that degeneracy can support pluripotentiality. Investigations of arm-leg coordination in breaststroke swimming have emphasized that degeneracy can support pluripotentiality as it reflects greater flexibility of a coordination pattern, i.e., higher range of functions, such as coping with a larger range of aquatic resistance in order to swim faster (Komar et al., 2015) and to optimize the glide by minimizing active drag (Seifert et al., 2014a). These findings illustrated how, some structures slightly mobilized under one set of constraints may potentially become much more mobilized under another set of constraints (Mason, 2014).

REFERENCES

Davids, K., Glazier, P. S., Araújo, D., and Bartlett, R. M. (2003). Movement systems as dynamical systems: the functional role of variability and its implications for sports medicine. *Sports Med.* 33, 245–260. doi: 10.2165/00007256-200333040-00001 PMID:12688825

Edelman, G. M., and Gally, J. A. (2001). Degeneracy and complexity in biological systems. *Proc. Natl. Acad. Sci. U.S.A.* 98, 13763–13768. doi: 10.1073/pnas.231499798 PMID:11698650

Komar, J., Chow, J. Y., Chollet, D., and Seifert, L. (2015). Neurobiological degeneracy: supporting stability, flexibility and pluripotentiality in complex motor skill. *Acta Psychol.* 154, 26–35. doi: 10.1016/j.actpsy.2014.11.002

Mason, P. (2014). Degeneracy: demystifying and destigmatizing a core concept in systems biology. *Complexity* 20, 12–21. doi: 10.1002/cplx.21534

Noppeney, U., Friston, K. J., and Price, C. J. (2004). Degenerate neuronal systems sustaining cognitive functions. *J. Anat.* 205, 433–442. doi: 10.1111/j.0021-8782.2004.00343.x PMID:15610392

Price, C. J., and Friston, K. J. (2002). Degeneracy and cognitive anatomy. *Trends Cogn. Sci.* 6, 416–421. doi: 10.1016/S1364-6613(02)01976-9

Seifert, L., Komar, J., Araújo, D., and Davids, K. (2016). Neurobiological degeneracy: a key property for functional adaptations of perception and action to constraints. *Neurosci. Biobehav. Rev.* 69, 159–165. doi: 10.1016/j.neubiorev.2016.08.006 PMID:27506266

Seifert, L., Komar, J., Crettenand, F., and Millet, G. (2014a). Coordination pattern adaptability: energy cost of degenerate behaviors. *PLoS ONE* 9:e107839. doi: 10.1371/journal.pone.0107839

Seifert, L., Wattebled, L., Herault, R., Poizat, G., Adé, D., Gal-Petitfaux, N., et al. (2014b). Neurobiological degeneracy and affordance perception support functional intra-individual variability of inter-limb coordination during ice climbing. *PLoS ONE* 9:e89865. doi: 10.1371/journal.pone.0089865

Whitacre, J. M. (2010). Degeneracy: a link between evolvability, robustness and complexity in biological systems. *Theor. Biol. Med. Model.* 7, 6. doi: 10.1186/1742-4682-7-6 PMID:20167097

Moving from Biology to Behavior II: Leveraging Phenotypic Plasticity to Identify Signatures of Behavioral Fitness

Paula L. Silva

Center for Cognition, Action & Perception, University of Cincinnati, Cincinnati, OH, United States
paula.silva@uc.edu

A central goal of sports training and rehabilitation is to develop athletic resilience. A resilient system is one that can maintain their current form when disturbed by external perturbations or stresses (Nemeth, 2008). We propose, therefore, that an athlete can be considered resilient if she demonstrates the ability to sustain performance and maintain physical integrity under the variable and often unpredictable conditions that characterize sports contexts. This ability is supported by a movement system whose elements (from neurons to body segments) are dynamically arranged and rearranged into context sensitive coordinative structures assembled to preserve desired functional effects (Kelso, 1986). We propose, therefore, that a resilient athlete lives in a "readiness" state that allows for swift changes in her functional structure (e.g., movement patterns) if the situation demands it. The capability of biological systems to change structure due to contextual influence is called phenotypic plasticity (Agrawal, 2001). Phenotypic plasticity has been demonstrated in a broad range of systems through assessment of change in isolated physical properties and/or biochemical processes as a function of specific types of stress. For example, plants change the number of defense glands in response to the number of attacking herbivores (Agrawal, 2001), and biochemical responses are modified in response to drug dosage (Calabrese and Mattson, 2011). Response curves can be considered fitness profiles that indicate to what extent the target function would thrive under various amounts of stress. Importantly, fitness profiles can be used to develop specific guidelines to optimize local responses to stress and promote better adaptability of biological systems. In this paper, I will present our team's effort to scale up the phenotypic plasticity approach from biology to behavior using the conceptual framework and tools of non-linear dynamics. Our goal is to obtain behavioral fitness profiles for relevant athletic tasks (e.g., collision avoidance) and use these profiles to leverage innovative, personalized, injury prevention and performance enhancement programs. The starting point of this endeavor was to identify groups of individuals known differ in behavioral fitness and to observe how they adapt perceptual-motor strategies to preserve performance when "stressed" by variations in task demands. The specific aim of this paper is to present initial results and lessons from studies that captured dynamical features of behavioral fitness at the level of multi-segmental dynamics. We hypothesized that reduced fitness (in particular, low functional and/or structural resilience) would be related to reduced adaptability of multi-segmental coordinative structures supporting task performance. We tested this hypothesis in two studies in which participants with low and high behavioral fitness performed cyclical motor tasks: a reciprocal aiming task that involved moving a hand-held tool back and forth between targets in the upright position; and a balance task that involved tracking the movement of a square target in single leg stance. The positions of body segments most directly involved with the tasks were captured over time. Cluster phase analysis, previously validated to characterize multi-agent dynamics (Frank and Richardson, 2010), was adapted to characterize the multi-segmental dynamics supporting task performance. This analysis yielded (a) an overall measure of the degree of coordination among a group of selected body segments; and (b) measures of the degree of coordination between each body segment and the whole group of body segments, hereafter referred to as segment-group coordination. While (a) reflects the internal coherence or stability of the coordinative structure supporting task performance, (b) provides indices of the degree and pattern of integration of each component body segment into the coordinative structure. In line with the phenotypic plasticity approach, we measured the changes in (a) and (b) as participants were "stressed" by manipulations of task demands (target size for the reaching task and target frequency for the balance task). Results showed that groups of participants with high behavioral fitness displayed significantly greater changes in overall coherence of the coordinative structure as a function of task demands than those with low behavioral fitness (e.g., athletes with high risk of injury). Additionally, participants with high behavioral fitness demonstrated significantly greater adjustments in the degree of integration and segregation of specific body segments into the coordinative structure and greater intermittency in segment—group coordination. Results suggest that resilience is predicated on poised (metastable) coordinative structures that stabilize desired functional effects through a smooth process of annihilation and recruitment of degrees of freedom that befits contextual conditions. Importantly, differences in multi-segmental dynamics between groups with high and low behavioral fitness were particularly evident at high stress conditions, suggesting that resilience is not intrinsically determined. Therefore, signatures of behavioral fitness (or lack thereof) can best be determined by "stressing" the system under at least two, but ideally various task and context conditions. Our next steps, currently underway, is to identify and create fitness profiles of perceptual-motor and neuromechanical mechanisms that underlie athletes' ability to effectively adapt their multi-segmental dynamical organization in response to contextual variations. We expect that these fitness profiles, once fully developed, will support the identification of the optimal type and range of challenges required to build athletic resilience and, better yet, to promote behavioral antifragility or growth of performance under stress.

REFERENCES

Agrawal, A. A. (2001). Phenotypic plasticity in the interactions and evolution of species. *Science (New York, N.Y.)* 294, 321–326. doi: 10.1126/science.1060701 PMID:11598291

Calabrese, E. J., and Mattson, M. P. (2011). Hormesis provides a generalized quantitative estimate of biological plasticity. *J. Cell Commun. Signal.* 5, 25–38. doi: 10.1007/s12079-011-0119-1 PMID:21484586

Frank, T. D., and Richardson, M. J. (2010). On a test statistic for the Kuramoto order parameter of synchronization: with an illustration for group synchronization during rocking chairs. *Physica D* 239, 2084–2092. doi: 10.1016/j.physd.2010.07.015

Kelso, J. A. S. (1986). Pattern formation in speech and limb movements involving many degrees of freedom. *Exp. Brain Res.* 15, 105–128.

Nemeth, C. P. (2008). "Resilience engineering: the birth of a notion," in *Resilience Engineering Perspectives*, Vol. 1, eds E. Hollnagel, C. P. Nemeth, and S. Dekker (Burlington, VT: Ashgate Publishing Ltd), 5–6.

Training Methods in Team Sports—From a Complex Systems' Theory to Practice

Bruno Travassos[1,2]

[1]Departamento de Ciências do Desporto, Universidade da Beira Interior, Covilhã, Portugal
[2]Research Center in Sports Sciences, Health and Human Development, CIDESD, CreativeLab Research Community, Vila Real, Portugal
bfrt@ubi.pt

Introduction: Team ball sports like futsal (indoor association football) are considered complex adaptive systems in which players' and teams' performance emerge from the relationship between individual, task and environment constraints (Davids et al., 2005). Understanding how performance emerges in complex systems like futsal is to understand how different players with different capabilities (physiological, tactical, technical) interact under task (game rules, different game systems) and environment (home-away, winning losing teams) constraints to make emerge functional, dyadic and collective spatiotemporal patterns of relations between teammates and with opponents (Travassos et al., 2011). In the past years, grounded on the main ideas of complex systems a lot of works (Travassos et al., 2012a; Vilar et al., 2013; Corrêa et al., 2016) have been developed, through the use of positional data, with the aim to capture the informational constraints that guide players and teams tactical behaviours and also the emergent patterns of coordination that characterizes and sustain teams' performance in futsal. Such research have identified interesting spatial–temporal relations between players' distances, angles, spaces covered or alignments with the goal, or the ball that help coaches to really understand the tactical behaviours of players and teams based on the coach model developed. Also, to characterize the game demands, previous research have been developed to measure the physical and physiological demands of training sessions and competitions through the measure of external and internal workload of players (Barbero-Alvarez et al., 2008; Castagna et al., 2009). However, despite of both approaches revealing important contributions to improve the understanding about performance of futsal players and teams, many of them really captured the performance in a complex perspective with transfer to the practice. To really understand performance of players and teams in a complex system, perspective is to understand the impact of different game constraints on physiological, technical, and tactical variables. This area of work is crucial not only for improving the understanding of game demands and players/teams' performance, but also for intervention of coaches on the design of effective practice tasks that ensure a maximum transfer between training sessions and competition (Travassos et al., 2012b). To improve the transfer between practice tasks and performance environments, the design of practice tasks should account with the idea of representative design of practice task (Travassos et al., 2012b). This concept emphasizes the correspondence between the demands of competition and the structure inherent to the training exercises across practice sessions. In practice, from the perspective of complex systems, the variations on players or teams' performance at a given game or practice task is influenced by the constraints that are acting upon it (Davids et al., 2005). However, the concept of representative design and such interactions between manipulated constrains and performance has been discussed only in the perspective of the effects on tactical behaviours or physiological performance in separated perspectives. In this communication, we aimed to combine our experience as high-performance Futsal coach and researcher to present some ideas regarding the application of the notion of representative design in practice. Data used to evaluate the transfer between practice and performance environment as a coach will be present and compared with previous research.

Discussion and conclusion: Based on previous assumptions, the design of representative tasks need to be supported by a great knowledge about the effects of manipulations of task constraints in different aspects of performance. Further research is required on this topic by considering the effects of such manipulations in different levels of players and teams' expertise. More than that, task constraints manipulations should not be defined in a general way, but according with a strategic game model defined by the coach. Further knowledge is required to really capture the informational constraints used by coaches and to measure the impact of such strategic variations of players' and teams' game demands.

REFERENCES

Barbero-Alvarez, J. C., Soto, V. M., Barbero-Alvarez, V., and Granda-Vera, J. (2008). Match analysis and heart rate of futsal players during competition. *J. Sports Sci.* 26, 63–73. doi: 10.1080/02640410701287289 PMID:17899472

Castagna, C., D'Ottavio, S., Granda-Vera, J., and Barbero-Alvarez, J. C. (2009). Match demands of professional futsal: a case study. *J. Sci. Med. Sport* 12, 490–494. doi: 10.1016/j.jsams.2008.02.001 PMID:18554983

Corrêa, U. C., de Pinho, S. T., da Silva, S. L., Clavijo, F. A. R., Souza, T. D. O., and Tani, G. (2016). Revealing the decision-making of dribbling in the sport of futsal. *J. Sports Sci.* 34, 2321–2328. doi: 10.1080/02640414.2016.1232488 PMID:27868480

Davids, K., Araújo, D., and Shuttleworth, R. (2005). "Applications of dynamical systems theory to football," in *Science and Football V: The Proceedings of the Fifth World Congress on Sports Science and Football*, eds T. Reilly, J. Cabri, and D. Araújo (Lisboa, Portugal: Routledge), 537–550.

Travassos, B., Araújo, D., Duarte, R., and McGarry, T. (2012a). Spatiotemporal coordination patterns in futsal (indoor football) are guided by informational game constraints. *Hum. Mov. Sci.* 31, 932–945. doi: 10.1016/j.humov.2011.10.004

Travassos, B., Duarte, R., Vilar, L., Davids, K., and Araújo, D. (2012b). Practice task design in team sports: Representativeness enhanced by increasing opportunities for action. *J. Sports Sci.* 30, 1447–1454. doi: 10.1080/02640414.2012.712716 PMID:22871067

Travassos, B., Araújo, D., Vilar, L., and McGarry, T. (2011). Interpersonal coordination and ball dynamics in futsal (indoor football). *Hum. Mov. Sci.* 30, 1245–1259. doi: 10.1016/j.humov.2011.04.003 PMID:21683464

Vilar, L., Araújo, D., Davids, K., Correia, V., and Esteves, P. T. (2013). Spatial-temporal constraints on decision-making during shooting performance in the team sport of futsal. *J. Sports Sci.* 31, 840–846. doi: 10.1080/02640414.2012.753155 PMID:23244400

Emergent Coordination in Joint Interception

Frank T. J. M. Zaal[1], Niek H. Benerink[2,3], Daphne van Opstal[1], Rémy Casanova[2], Nathalie Bonnardel[3], Reinoud J. Bootsma[2]

[1]*Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, Netherlands*

[2]*Institut des Sciences du Mouvement, Aix-Marseille Université, CNRS, Marseille, France*

[3]*PsyCLE, Aix-Marseille Université, Aix-en-Provence, France*

f.t.j.m.zaal@umcg.nl

Introduction: In many situations, in which daily life people show coordinated behaviour to attain a shared goal. There are many situations in which people have to work together (e.g., lifting a sofa) or take turns (e.g., two individuals both approaching an exit). In team sports, the examples abound: for instance, baseball players coordinating in fielding (Gray et al., 2017), volleyball players coordinating in receiving a serve (Paulo et al., submitted) or football players coordinating to best organize their team (Memmert et al., 2017). Here, we consider a "doubles-pong" task, modelled after sports situations in which teams of players have to make sure that one, and only one, team member intercepts a ball (e.g., receiving a volleyball serve). We contrast two potential ways in which team coordination comes about: based on an explicit division of labor or emerging from the coordination dynamics.

Methods: Two players each controlled a paddle on a shared screen (see Figure 1). Their task was to make sure that a ball that moved from the top to the bottom of the screen would be intercepted by one on them, while also avoiding a collision between the paddles (Benerink et al., 2016, submitted). Importantly, the only available communication between the two players was through vision of their shared screen; they were not allowed any verbal communication, before or during their game.

Results and discussion: We considered two ways that would potentially lead to successful team behaviour. A first way would be to use a tacitly understood spatial boundary along the interception axis, such that the left player would take the balls arriving left of the boundary and the right player would be responsible for balls right of the boundary. Indeed, in five out of six teams in a first study, we were able to establish a boundary close to halfway in between the initial positions of both players' paddles (Benerink et al., 2016). The sixth team showed a boundary a little bit closer to the paddle of the player who had been least successful in the preceding training session. This could be taken to suggest that the player with better interception capabilities (i.e., better performance in the training session) took responsibility of a larger interception domain. We have tested this in a separate study, the data of which are currently being analysed. Returning to the boundary of the five teams in the first study, the finding that this turned out to be roughly halfway the initial paddle positions coincided with the boundary being roughly at the vertical midline of the shared screen. Therefore, in a second study (Benerink et al., submitted), we varied the initial position of the right player to be at one of two positions randomly in each trial. This manipulation effectively removed the confound of the two options for a tacitly agreed-on boundary mentioned before. The results of this study demonstrated that players do not seem to use either of these two rationales. The boundaries, as we determined these using logistic regression, varied across teams of players in ways not easily reconcilable with the hypotheses that teams based their decisions on who would take which ball using a boundary either halfway the screen or halfway in between the initial positions of their paddles. A second way in which the boundaries between the interception domains of the two players might be understood that these emerge from the coordination between the two players and the ball. From this perspective, the boundaries would not be the basis of the joint decision process of both players but rather the outcome. That is to say, the boundaries can be determined post-hoc, but are not playing an explicit role for the two players moving to make a successful interception. In line with such an account, Benerink et al. (2016) suggested that the division of labour between the two players emerges from the continuous visual coupling of the player-controlled paddles and the ball. On many trials, both players initiated a movement, which was then aborted by one player when the other player was on an interception course. That one of the players would be moving such that he or she would be able to reach the interception location in time was specified through

FIGURE 1: The Setup used in the studies (Benerink et al., 2016, submitted)

the changing triangular relation among ball and paddles. This model accounted for many of the observed details regarding the boundaries. Furthermore, the model also accounted for the varying patterns observed in the second study, in which the initial paddle positions were manipulated (Benerink et al., submitted).

Conclusion: In conclusion, when two players have to coordinate to attain a shared goal, the observed decision making might be based on tacit agreements or might emerge from the dynamic interactions of the system of players and ball. We suggest a prominent role of the latter type of joint decision making.

REFERENCES

Benerink, N. H., Zaal, F. T. J. M., Casanova, R., Bonnardel, N., and Bootsma, R. J. (2016). Playing "pong" together: emergent coordination in a doubles interception task. *Front. Psychol.* 7:1910. doi: 10.3389/fpsyg.2016.01910

Benerink, N. H., Zaal, F. T. J. M., Casanova, R., Bonnardel, N., and Bootsma, R. J. (submitted). *Division of Labor as an Emergent Phenomenon of Social Coordination: The Example of Playing Doubles-Pong.*

Gray, R., Cooke, N. J., McNeese, N. J., and McNabb, J. (2017). Investigating team coordination in baseball using a novel joint decision making paradigm. *Front. Psychol.* 8:907. doi: 10.3389/fpsyg.2017.00907 PMID:28638354

Memmert, D., Lemmink, K. A. P. M., and Sampaio, J. (2017). Current approaches to tactical performance analyses in soccer using position data. *Sports Med.* 47, 1–10. doi: 10.1007/s40279-016-0562-5 PMID:27251334

Paulo, A., Zaal, F. T. J. M., Seifert, L., Fonseca, S., and Araújo, D. (submitted). *Predicting Volleyball Serve-Reception at Group Level.*

ABSTRACTS ORAL FREE SESSIONS

The Relationship between Action Levels and Their Efficacy in Team Handball. Comparative Analysis in Children and Senior Teams

Gerard Lasierra Aguilà[1], David Carreras Villanova[1], Manuel Montoya Fernández[2], Antoni Planas Anzano[1]

[1]National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
[2]Qatar Handball Association, Doha, Qatar
glasierra@inefc.es

Introduction: We highlight the contributions from the sports analysis perspective: praxeology (Parlebas, 2008) and the structural model (Bayer, 1986). We likewise consider the disciplines which study the player and the sports team: the constructivist learning theories (López Ros and Sargatal, 2011), and the ecological dynamics and complex systems theories (Davids, 2016), in which we include the constraints-led approach (Renshaw et al., 2010) and its application, non-linear pedagogy (Chow et al., 2016). Based on this, we propose a systemic model to explain team sports (Lasierra, 2017), characterized by: (1) delimiting the competitive context as the scenario in which a certain arrangement of the sport's parameters is presented, and which leads to the emerging behaviour observed in players; and (2) distributing on three levels of action, the sport behaviour observed: individual, collective and systems. The following main objectives are raised in this research: (1) design a recording model allowing the elements which make up team handball to be described and related; and (2) compare, applying the same recording model, the characteristics of team handball competition in children and senior categories.

Methods: We selected the Observational Methodology (Anguera and Hernández Mendo, 2015), and following its guidelines, we chose a combined ad hoc system of field formats and system of categories, using an ideographic, specific and multidimensional research design. Dartfish TeamPro V.4.5 software was used as an observation and recording instrument to analyze seven senior male category matches (hereinafter, SEN) of the Spanish *Copa del Rey* (2012), and seven children male category matches (hereinafter, CHI) of the Spanish club championship (2012), generating type II data (concurrent and of the event). Bivariate descriptive and inferential statistical techniques are applied for the relational analysis of the data, adding the multivariate CHAID analysis of decision trees technique to the comparative analysis of groups.

Results: In relation to the first objective of the research, the results show a statistically significant relationship between:

- The order of occurrence of collective attacking procedures in each sequence: SEN ($\chi^2 = 152.625$; $p < 0.0005$; $V = 0.056$), CHI ($\chi^2 = 203.055$; $p < 0.0005$; $V = 0.078$).

- The final attacking play system and the collective attacking procedures: SEN ($\chi^2 = 49.563$; $p < 0.0005$; $V = 0.049$), CHI ($\chi^2 = 45.165$; $p < 0.0005$; $V = 0.058$).

- The collective attacking procedures and the specific attacking positions: SEN ($\chi^2 = 567.5$; $p = 0.001$; $V = 0.530$), CHI ($\chi^2 = 313.1$; $p = 0.001$; $V = 0.482$).

As regards the second objective, the most significant differences between the ABS and CHI categories (considered as a dependent variable) are showed by the independent variable criteria with the greatest intensity of prediction:

- In the situational framework, the difference in the score ($\chi^2 = 443.5$; $p = 0.000$).

- In the play systems framework, the defensive system ($\chi^2 = 529.7$; $p = 0.000$).

- In the collective procedures framework, the collective defensive procedures ($\chi^2 = 78.4$; $p = 0.000$).

- In the individual actions framework, the specific position of the initiating player with the ball ($\chi^2 = 57.7$; $p = 0.000$).

- In the effectiveness framework, the technical-tactical errors ($\chi^2 = 9.3$; $p = 0.002$).

Discussion and conclusion: Due to the lack of research that relates the different levels of action, as well as the absence of comparative analysis between categories of competition in team handball, they make it impossible to compare the results of this study. The following are the most important conclusions of the relational analysis (first objective):

- No differences are detected in attacking systems depending on the different defensive systems.

- Collective attacking procedures differ between the beginning and end of each sequence.

- An attacking error is associated with the blocking and doubling defensive procedures.

- The activation of procedures without ball is associated with success of the attack.
- First-line attacking players produce a greater number of successes and of errors, the second attacking line being more effective.

The following are the most important conclusions of the comparative analysis between SEN and CHI (second objective):

Significant differences are established between SEN and CHI in:

- Greater variety in defensive play systems in CHI.
- Collective defensive procedures differ.
- Collective attacking procedures in SEN are linked to interchanging play while in CHI to positional play.
- Procedures without ball are more frequently used in SEN.
- CHI is characterized by a greater occurrence of ball losses.

No significant differences are established between SEN and CHI in:

- Duration of the play sequences.
- Type of collective attacking procedures.
- Any of the following effectiveness criteria: success of the throw, success of attack, error of the rules, error on throwing.

REFERENCES

Anguera, M. T., and Hernández Mendo, A. (2015). Técnicas de análisis en estudios observacionales en ciencias del deporte. *Cuadernos de Psicología Del Deporte* 15, 13–30. doi: 10.4321/S1578-84232015000100002

Bayer, C. (1986). *La enseñanza de los juegos deportivos colectivos*. Barcelona: Hispano-Europea.

Chow, J. Y., Davids, K., Button, C., and Renshaw, I. (2016). *Nonlinear Pedagogy in Skill Acquisition. An Introduction*. Abingdon, Oxon: Routledge.

Davids, K. (2016). "Interpersonal coordination tendencies in competitive sport performance: issues and trends for future research," in *Interpersonal Coordination and Performance in Social Systems*, eds P. Passos, K. Davids, and J. Y. Chow (Abingdon, Oxon: Routledge), 323–337.

Lasierra, G. (2017). *Balonmano: la relación entre los sistemas de juego, los procedimientos colectivos y su eficacia (Tesis doctoral)*. Lleida: Universitat de Lleida- INEFC-Lleida.

López Ros, V., and Sargatal, J. (2011). in *La táctica individual en los deportes de equipo*, eds V. L. ópez Ros and J. Sargatal (Girona: Universitat de Girona. Càtedra d'Esport i d'Educació Física de la UdG).

Parlebas, P. (2008). *Juegos, deporte y sociedades. Léxico de Praxiología Motriz*. Barcelona: Paidotribo.

Renshaw, I., Davids, K., and Savelsbergh, G. J. (eds) (2010). *Motor lEARNING in Practice. A Constraints-Led Approach*. London: Routledge.

Anaerobic Threshold or Cardiorespiratory Reconfigurations with Workload Accumulation?

S. Bellmunt[1], Sergi Garcia-Retortillo[1,2], C. Javierre[3], J. L. Ventura[3], R. Hristovski[2], N. Balagué[1]

[1]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), Universitat de Barcelona (UB), Barcelona, Spain

[2]Complex Systems in Sport Research Group, School of Health and Sport Sciences (EUSES), Universitat de Girona, Salt, Spain

[3]Department Physiological Sciences, Universitat de Barcelona (UB), Barcelona, Spain

[4]Complex Systems in Sport Research Group, Faculty of Physical Education, Sport and Health, Ss. Cyril and Methodius University of Skopje, Skopje, Macedonia

sgarciaretortillo@gmail.com

Introduction: The anaerobic threshold (AT) and specifically its non-invasive determination, the ventilatory threshold (VT), is commonly assessed during cardiorespiratory fitness tests to define the limits of exercise intensity that can be tolerated in time. Determined through changes in ventilatory equivalents and other gas exchange variables during exercise, the VT has been related to metabolic acidosis (Wasserman, 1986). However, the methodological and theoretical bases of the concept are still controversial (Abreu et al., 2016). Investigating the cardiorespiratory coordination (CRC) during cardiorespiratory exercise testing through a principal component analysis approach (PCA), Balagué et al. (2016) and Garcia-Retortillo et al. (2017) have pointed to a potential connection between VT and CRC. The authors consider the first principal component (PC_1) as the CRC variable because it accounts for as much of the co-variation as possible among the registered cardiorespiratory variables. Changes of PC_1 scores are informative about the reconfigurations of the cardiorespiratory system during exercise. In order to improve the understanding about the concept of AT and its determination during cardiorespiratory exercise testing, the aim of this research was to investigate the agreement between the determination of AT through VT and PC_1 scores time series.

Methods: Twenty-one healthy adults were evaluated through a progressive and maximal cardiorespiratory cycling test. Participants started pedalling at 0 W and the workload was increased by 25 W/min in males and 20 W/min in females, until they could not maintain the prescribed cycling frequency of 70 rpm for more than 5 consecutive seconds. A PCA of selected cardiovascular and respiratory variables was performed to evaluate CRC. Time series of PC_1 scores of all participants were established and its inflexion points were determined through visual inspection of time series graphs. VT was determined by means of the O_2 and CO_2 ventilatory equivalents method (Reinhard et al., 1979). Both PC_1 inflexion points and VT were determined by two researchers

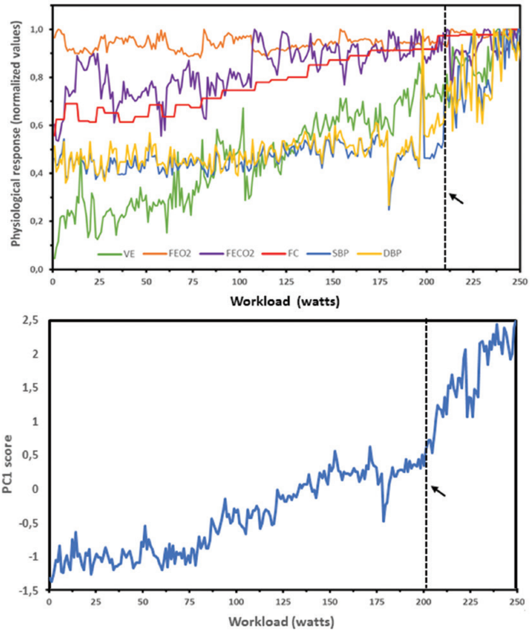


FIGURE 1: Typical example of the reduction of cardiorespiratory variables to time series of cardiorespiratory coordination variables (PCs). Upper graph: original time series of the six selected cardiorespiratory variables. Bottom graph: time series of first PC (PCi) scores (standardized z-values in the space spanned by PCs). The doted line shows the occurrence of VT in upper graph and the inflexion point of PCi time series in bottom graph.

independently and in a blinded fashion. Maximal oxygen consumption (VO_{2max}) and maximal workload (W_{max}) were also registered during the test. The mean of absolute differences and the Bland-Altman technique were used to evaluate the agreement between VT and the inflexion point of PC_1 scores.

Results: Figure 1 shows a typical example of the reduction of cardiorespiratory variables to a time series of PC_1 scores. Participants performed an average of 43.5 ± 12.5 ml/kg/min and 310.3 ± 77.8W. While the mean workload corresponding to VT was 243.5 ± 58.4W, the inflexion point of PC1 was found in a mean workload of 244.8 ± 66.8W. Significant correlations were revealed between VT and PC_1 ($r = 0.85$, $p < .001$). Moreover, the Bland-Altman technique revealed agreement between VT and PC_1 scores inflexion points, based on the low mean of differences (see Figure 2).

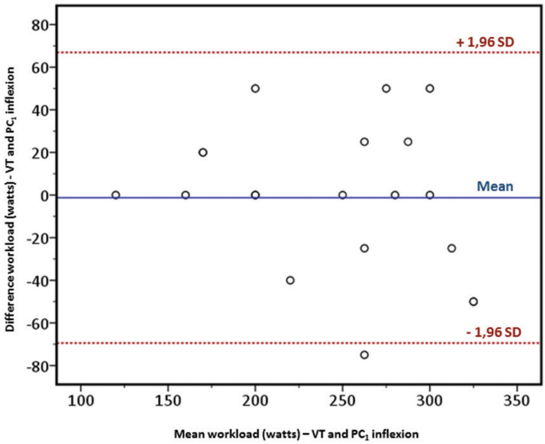


FIGURE 2: Bland and Altman analysis with continuous line shows the bias between the workload corresponding to VT and PC_1 inflexion, and the dotted line shows the confidence limit given by the mean ± 1.96 SD. VT, ventilatory threshold; PC_a, first principal component.

Discussion: The significant correlations between workload values at VT and PC_1 inflexion points found in this study, as well as the acceptable agreement revealed by the Bland-Altman technique, indicate that PC_1 might be an applicable method to identify AT in healthy adults. In conclusion, given that to date no widely accepted agreement on methodological and theoretical basis of VT has been settled (Binder et al., 2008; Abreu et al., 2016), and since its occurrence has been shown to be induced by several non-simultaneous cardiorespiratory mechanisms with a lack of hierarchy between them (Walsh and Banister, 1988), the determination of AT through CRC and specifically through PC_1 dynamics could be a suitable strategy to complement cardiorespiratory exercise testing evaluation.

REFERENCES

Abreu, P., Mendes, S. V. D., Leal-Cardoso, J. H., and Ceccatto, V. M. (2016). Anaerobic threshold employed on exercise training prescription and performance assessment for laboratory rodents: a short review. *Life Sci.* 151, 1–6. doi: 10.1016/j.lfs.2016.02.016 PMID:26860893

Balagué, N., González, J., Javierre, C., Hristovski, R., Aragonés, D., Álamo, J., et al. (2016). Cardiorespiratory coordination after training and detraining. A principal component analysis approach. *Front. Physiol.* 7:35. doi: 10.3389/fphys.2016.00035 PMID:26903884

Binder, R. K., Wonisch, M., Corra, U., Cohen-Solal, A., Vanhees, L., Saner, H., et al. (2008). Methodological approach to the first and second lactate threshold in incremental cardiopulmonary exercise testing. *Eur J Cardiovasc Prev Rehabil.* 15, 726–734. doi: 10.1097/HJR.0b013e328304fed4

Garcia-Retortillo, S., Javierre, C., Hristovski, R., Ventura, J. L., and Balagué, N. (2017). Cardiorespiratory coordination in repeated maximal exercise. *Front. Physiol.* 8:387. doi: 10.3389/fphys.2017.00387 PMID:28638349

Reinhard, U., Müller, P. H., and Schmülling, R. (1979). Determination of anaerobic threshold by the ventilation equivalent in normal individuals. *Respiration* 38, 36–42. doi: 10.1159/000194056 PMID:493728

Walsh, M. L., and Banister, E. W. (1988). Possible mechanisms of the anaerobic threshold. A review. *Sports Med.* 5, 269–302. doi: 10.2165/00007256-198805050-00001

Wasserman, K. (1986). The anaerobic threshold: definition, physiological significance and identification. *Adv. Cardiol.* 35, 1–23. doi: 10.1159/000413434

Collective Tactical Patterns in Football SSGs by Means of hPCA

Albert Canton[1], Carlota Torrents[1], Ángel Ric[1], Bruno Gonçalves[2], Jaime Sampaio[2], José Luís Arjol[3], Robert Hristovski[4]

[1]Complex Systems in Sports Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
[2]Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, CreativeLab Research Community, Vila Real, Portugal
[3]San Jorge University, Zaragoza, Spain
[4]Faculty of Physical Education, Sport and Health, Saint Cyril and Methodius University, Skopje, Macedonia
acanton@inefc.es

Introduction: In order to attend the demands of football and improve the performance of the players, coaches rely on the use of the Small-Sided Games (SSGs) (Aguiar et al., 2013). During a football match, several movement coordination patterns that arise can be detected by means of hierarchical Principal Component Analysis (hPCA) (Ric et al., 2016). The aim of this study was to identify the tactical patterns that define each team in football SSGs using hPCA.

Methods: The participants in this study were fifteen professional male under 23 football players. Three teams (A, B and C), of four outfield players plus a goalkeeper, played three SSGs against each other. These teams were configured according to the coach criteria, to ensure a comparable performance (Aguiar et al., 2013). All SSGs were played on a natural pitch measuring 40 m × 45 m. Each game involved 5-min periods of play separated by 3-min of passive rest. Positioning-derived variables (Table 1) were determined using latitude and longitude coordinates exported from 5 Hz non-differential global positioning system (SPI ProX, GPSports, Canberra, ACT, Australia) and computed using dedicated routines in Matlab® (Folgado et al., 2014). The local Institutional Research Ethics Committee approved the study, which also conformed to the recommendations of the Declaration of Helsinki.

Results: The number of significant first-level principal components was determined by identifying between 12 and 17 Principal Components (PCs) that accounted for ≥80% of the explained variance (Joliffe, 2002) for each SSG. The component score matrix of the first-order PCs was the subjected to a further higher-order analysis revealing a higher-order structure. A significant hierarchical structure was obtained, resulting between three- and five- order PCs, depending on the game. Then, the highest level PC was obtained with only one PC which captures the most robust and stable structure of associations within the data (Table 1). Tucker's congruence coefficient was used to determine the degree of similarity between highest level PCs. The structures of team A PCs showed non-congruence comparing when they compete with team B and team

C (r_c = 0.48). Despite not having a significant congruence, there are similarity traits in all variables except in team length, showing a higher compaction against team C. The structures of team B PCs showed non-congruence comparing when they compete with team A and C (r_c=0.05). This results show that tactical behaviour base of team B would change depending on the opponent team. The structures of team C showed congruence comparing when they compete with team A and B (r_c=0.89). It almost shows a total congruence in all variables in exception with the Spread of the team, which against team A is in contraction and against team C is in expansion.

Discussion and conclusion: Findings of this study suggest that tactical behaviours in SSGs are constrained, in different ways, by the interaction of both teams. The Tucker's congruence coefficient shows that teams A and B adapt their tactical behaviour when they play against another team, while team C plays with a very similar tactical pattern independently of the rival. This stability in the tactical pattern of team C may be explained by their coordination or synergic relation between players and/or the positive scores (AvsB = 2-0; AvsC = 0-4; BvsC = 0–2). It would be interesting to repeat this kind of situation periodically to see if the structures of a team are the same or are modified later in time. And even, they could be modified, changing a key player to see if this variation modifies the collective behaviour of the team and which new (or not) synergies are established amongst them, helping coaches to better understand their own team.

TABLE 1: Tactical behaviours resulting from the positioning-derived variables that define the highest-level of PC of each SSG and team.

Positioning-derived variables		**PC Ab**	**PC Ac**	**PC aB**	**PC Bc**	**PC aC**	**PC bC**
Pitch sector[a]	1	−0.65	−1.01	−0.44	−0.92	−1.10	−0.99
	2	−0.23	0.27	−0.06	−0.70	−0.73	−0.26
	3	2.66	1.38	2.06	0.47	1.19	2.48
	4	−1.20	0.76	−1.09	2.34	1.95	0.00
	5	−0.30	−0.94	−0.28	−0.79	−0.85	−0.79
	6	0.65	−1.08	−0.44	−0.92	−1.10	−0.99
Pitch corridor[b]	1	−0.65	−1.08	−0.44	−0.92	−1.10	−0.99
	2	−0.39	−0.99	−0.44	−0.71	−0.79	−0.98
	3	0.02	0.99	−1.34	3.41	2.37	3.21
	4	1.46	2.34	2.51	−0.20	0.97	0.11
	5	−0.17	−0.80	−0.14	−0.91	−0.97	−0.92
	6	−0.65	−1.08	−0.44	−0.92	−1.10	−0.99

(*Continued*)

TABLE 1: (Continued)

Positioning-derived variables		PC Ab	PC Ac	PC aB	PC Bc	PC aC	PC bC
Centroid speed (m/s)	–2	–0.45	–0.56	–0.72	–0.78	–0.72	–0.73
	–1	0.33	–0.44	–0.46	–0.38	0.03	–0.25
	0	–0.16	0.32	–1.52	0.10	0.52	0.48
	0	0.64	0.72	2.96	1.60	0.68	0.66
	1	–0.33	0.20	–0.35	–0.39	–0.42	–0.01
	2	–0.40	–0.85	–0.17	–0.68	–0.71	–0.72
Team length (m)	<4	–0.62	–1.03	–0.47	–0.90	–1.06	–0.98
	8	-0.45	-0.03	-0.47	–0.57	–0.73	-0.38
	12	–1.15	1.43	0.38	0.01	0.01	0.49
	16	2.54	0.35	0.87	1.36	0.69	0.65
	20	–0.02	–0.47	–0.01	0.20	0.42	–0.13
	>20	–0.66	–0.87	–0.56	–0.63	0.04	–0.21
Team width (m)	<12	–0.22	0.32	–0.46	–0.32	–0.72	–0.76
	16	0.58	1.53	0.04	0.13	0.51	0.55
	20	–0.76	–0.38	0.09	0.41	1.01	0.76
	24	0.30	–0.42	0.43	–0.12	0.19	0.06
	28	0.24	–0.88	–0.01	0.20	–0.77	–0.27
	>28	–0.50	–0.77	–0.34	–0.81	–0.85	–0.90
Spread (m/s)	–1	–0.53	–0.88	–0.46	–0.55	–0.72	–0.67
	–0.5	–0.09	–0.45	–0.37	–0.17	–0.22	–0.38
	0	–0.58	–0.81	1.79	0.34	0.24	0.64
	0	1.19	1.06	–1.21	0.60	0.85	0.55
	0.5	0.28	–0.19	0.38	0.14	0.07	0.20
	1	–0.65	–0.97	–0.37	–0.90	–0.86	–0.90

Values >1 highlighted in dark grey. Highest values of a variable highlighted in light grey when scores are not upper than 1

[a]From defensive (1) to offensive (6)

[b]From right (1) to left (6).

REFERENCES

Aguiar, M., Botelho, G., Gonçalves, B., and Sampaio, J. (2013). Physiological responses and activity profiles of football small-sided games. *J. Strength Cond. Res.* 27, 1287–1294. doi: 10.1519/JSC.0b013e318267a35c PMID:22820211

Brummelhuis, R., Cordoba, A., Quintanilla, M., and Seco, L. (2002). Principal component value at risk. *Math. Fin*. 12(1), 23–43. doi: 10.1111/1467-9965.00002

Folgado, H., Lemmink, K. A., Frencken, W., and Sampaio, J. (2014). Length, width and centroid distance as measures of teams tactical performance in youth football. *Eur. J. Sport Sci.* 14, S487–S492. doi: 10.1080/17461391.2012.730060 PMID:24444244

Joliffe, I. T. (2002). *Principal Component Analysis*. Heidelberg: Springer.

Ric, A., Torrents, C., Gonçalves, B., Sampaio, J., and Hristovski, R. (2016). Soft-assembled multilevel dynamics of tactical behaviors in soccer. *Front. Psychol.* 7:1513. doi: 10.3389/fpsyg.2016.01513 PMID:27761120

Effects of a Differential Learning and Physical Literacy Training Program on Forwards Performance (Youth Soccer)

Diogo Coutinho[1], Sara Santos[1], Bruno Gonçalves[1], Bruno Travassos[2], Del P. Wong[3], Wolfgang Schöllhorn,[4] Jaime Sampaio[1]

[1]*Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, CreativeLab Research Community, Vila Real, Portugal*

[2]*Department of Sports Sciences, University of Beira Interior, CIDESD, Vila Real, Portugal*

[3]*Sport Science Research Center, Shandong Sport University, Jinan, China*

[4]*Institute of Sport Science, Training and Movement Science, University of Mainz, Mainz, Germany*

diogoamcoutinho@gmail.com

Introduction: Soccer is a team sport, where two teams compete against each other in space and time to achieve advantage that allows to score a goal in the opponents' target. However, this aim is becoming increasingly more difficult to achieve, due to the increase in the defensive strategies and team compactness. These evidences have major implications, mainly for forwards, which are the players with the role for creating space for them or their team mates as well as to create scoring opportunities. As so, training programs should develop forward ability to disrupt the defensive balance, by increasing their motor variability and movement unpredictability (Gonçalves et al., 2014). Accordingly, the differential learning may emerge as a useful approach to develop players adaptability to unpredictable environments and increase their motor versatility (Schöllhorn et al., 2012; Santos et al., 2017). Moreover, considering the role of the physical capacities on goal scoring opportunities (Faude et al., 2012), coaches should also develop players fundamental movement skills that are achieved by the physical literacy assumptions. In fact, previous reports have shown improvements in the motor performance using the physical literacy as one of the tenets of the training program (Santos et al., 2017). Research describing the impact of these training programs on players' specific positional role is lacking. Therefore, the aim of the present study was to identify the effects of a training program sustained in differential learning and physical literacy on under-15 (U15) forward players' technical and tactical performances.

Methods: A total of 45 players participated in the study, whereby only the 18 forwards were retained for analysis. The 18 players were assigned to a control group ($n = 9$) and an experimental group ($n = 9$). Subjects from the experimental group were involved in a 10-month training program, twice a week for 25-min each session performed in the beginning of the session, based on physical literacy and differential learning approaches, whereas after the final of the program they joined the rest of the team and followed the normal training session. The control group participated in their usual training program, which was characterised by task repetition and coach task correction. For the data collection, a pre- and post- 5-a-side small-sided game were performed, during which players wore GPS devices and the games were video recorded. The in-game variables used to measure the effect of the training program were derived from the players' positional data: longitudinal and lateral regularities, distance and regularity to opponents' centroid and distance to nearest defender. Also, several technical actions were notated: successful pass, successful dribble, shots on target and goals. Magnitude-based inferences and precision of estimation were employed in data analysis.

Results: The subjects from the experimental group presented a likely ~17% increase in the distance to opponent centroid and of ~11% increase to the nearest defender compared to the control group. Interestingly, these subjects also showed an increase in the irregularity of the movement patterns in both lateral (likely ~11% more) and longitudinal (very likely ~26% more) compared to the control group (Figure 1). Finally, the program was also effective in the development of most of the technical variables, whereby there was a likely increase in the number of successful dribbles and goals, and a most likely increase in the number of shots to the target in the experimental group.

Discussion and conclusion: Overall, the results provide evidence that the training program was effective to develop both the tactical and technical performances. Although preliminary, the results may suggest that players may have become more

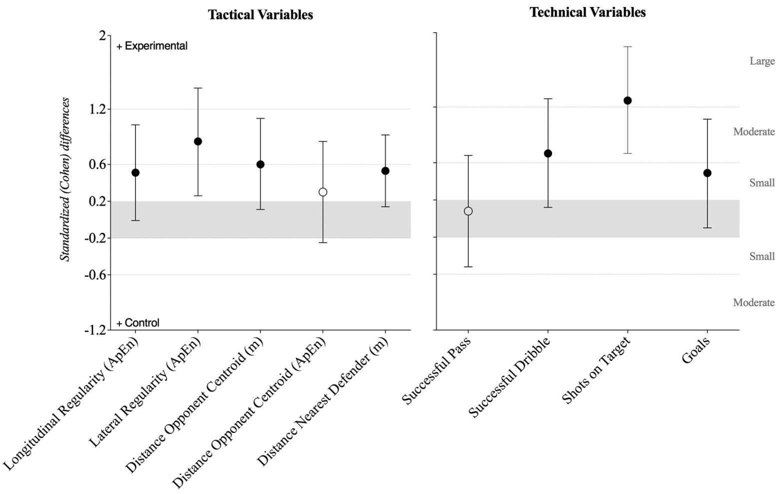


FIGURE 1: Standardized (Cohen's *d*) differences of positional and technical variables between the control and experimental groups (grey • dots represent higher values for the experimental group, while the ◯ represent unclear effects). Error bars indicate uncertainty in the true mean changes with 90% confidence intervals.

skillful in perceiving the available space, which allowed them to improve the distance to both opponents and nearest defender. In fact, previous reports showed that training programs sustained in differential learning and physical literacy improves the players' ability to use the environmental information (Santos et al., 2017). Moreover, the variability induced by these approaches may have led the players to exhibit more irregular movement patterns so that became more difficult for the defenders to anticipate. Furthermore, the players have also increased the number of successful actions related to the offensive process, which gives them more versatile tools to beat the defenders.

REFERENCES

Faude, O., Koch, T., and Meyer, T. (2012). Straight sprinting is the most frequent action in goal situations in professional football. *J. Sports Sci.* 30, 625–631. doi: 10.1080/02640414.2012.665940 PMID:22394328

Gonçalves, B., Figueira, B., Macas, V., and Sampaio, J. (2014). Effect of player position on movement behaviour, physical and physiological performances during an 11-a-side football game. *J. Sports Sci.* 32, 191–199. doi: 10.1080/02640414.2013.816761 PMID:24016056

Santos, S., Jiménez, S., Sampaio, J., and Leite, N. (2017). Effects of the Skills4Genius sports-based training program in creative behavior. *PLoS ONE* 12:e0172520. doi: 10.1371/journal.pone.0172520 PMID:28231260

Schöllhorn, W., Hegen, P., and Davids, K. (2012). The nonlinear nature of learning – a differential learning approach. *Open Sport. Sci. J.* 5, 100–112. doi: 10.2174/1875399×01205010100

Identifying Different Tennis Player Types: An Exploratory Approach to Interpret Performance Based on Player Features

Yixiong Cui[1], Miguel-Ángel Gómez[1], Bruno Gonçalves[2], Jaime Sampaio[2]

[1]Faculty of Physical Activity and Sport Sciences–INEF, Technical University of Madrid, Madrid, Spain
[2]Research Center in Sports Sciences, Health Sciences and Human Development (CIDESD), CreativeLab Research Community, Universidade de Trás-os-Montes e Alto, Vila Real, Portugal
amtf000cui@gmail.com

Introduction: Tennis is a complex and dynamic game where players constantly make decisions on maximizing the winning possibility. Previous studies have provided insights on how the environmental factors such as court surface (O'Donoghue and Ingram, 2001; Gillet et al., 2009) and set number (Maquirriain et al., 2016) could influence the player's tactics and match performance. Nevertheless, for an individual and multifaceted sport like tennis, the understanding of how different personal characteristics (e.g., height and weight) can affect the match-play remains somehow unclear, although it is recognizably useful to develop individualized training plans and strategies. Therefore, the aim of this study was two-folded: (i) to explore and classify tennis players with respect to their personal features, (ii) to analyze and interpret the difference of technical-tactical and physical performance for player types with new visualization techniques.

Method: Data related to players' characteristics were obtained from the official website of Association of Tennis Professional (ATP, www.atpworldtour.com), and they included: weight, height, playing experience, and handedness (left-handed or right-handed; one-handed backhand or two-handed backhand). Match statistics for 154 players contesting in 77 matches played in Hawk-Eye equipped court were collected from 2015 to 2016 Roland Garros tournament. A two-step cluster analysis with log-likelihood as the distance measure and Schwartz's Bayesian criterion was employed to classify players according to their weight, height, and handedness. Afterwards, descriptive discriminant analyses were performed for different player clusters, using twenty-nine match variables including serve and return, breakpoints, net, rally, and movement performance. Structure coefficients greater than |0.30| were interpreted as meaningful contributors for discriminant functions that differentiate player clusters. The analyses were done via IBM SPSS software (Armonk, NY, USA: IBM Corp.), and custom Matlab (MathWorks, Inc., MA, USA) routines were employed to generate the Convex hull area and Cluster dispersion index area of performance for each player type, using the discriminant scores. The Convex hull area is the smallest polygonal region that marks the players' performance of certain cluster group. Cluster dispersion index area demarcates the radial expansion of performance for each player cluster, and it is calculated using the mean distance from each player's discriminant score to the geometrical center of the corresponding cluster (see Figure 1).

Results: Four clusters of players were identified by the two-step cluster analysis. While the variable one- or two-handed backhand was the strongest cluster predictor, the playing experience was the weakest. 56 righty two-handed backhand players with shortest height (183.4 ± 5.2 cm), lowest weight (74.8 ± 3.8 kg) and 10.3 ± 3.6 years of experience were labeled as "Small-sized Righty Two-handed Players (SRT)"; 45 righty two-handed backhand players with longest height (192.9 ± 4.0 cm), heaviest weight (87.6 ± 5.7 kg), and 9.8 ± 3.0 years of experience were labeled as "Big-sized Righty Two-handed Players (BRT)"; 37 righty one-handed backhand players with medium height (184.4 ± 5.5 cm), medium weight (80.2 ± 6.9 kg), and 12.8 ± 3.2 years of experience were labeled as "Medium-sized Righty One-handed Players (MRO)," and 16 lefty two-handed backhand players with medium height (185.2 ± 5.5 cm), medium weight (81.4 ± 6.3 kg), and 11.8 ± 3.7 years of experience were labeled as "Lefty Two-handed Players (LT)." All player clusters were discriminated by fastest serve speed (structure coefficient = 0.69), first serve speed in deuce (SC = 0.55) and advantage court (SC = 0.31), ace in deuce (SC = 0.37) and advantage court (SC = 0.33), and second serve speed in advantage court (SC = 0.37). BRT players outperformed other players in all the above-mentioned variables expect for second serve speed in advantage court, which was dominated by LT players. SRT players performed worse in all these variables, while MRO players showed a better performance than SRT and LT players.

Discussion: Players' serve-related performance was influenced by the difference personal characteristics as taller and heavier player seemed to show big advantage in serving. However, lefty handed players could outperformed other players in second serve to advantage court by being able to open up more angle and generate more ball spins. Convex hull area (Figure 1B) showed that SRT players had more variation in performance. The Cluster dispersion index area demonstrated that MRO players had more similarity in match performance than the rest of the player clusters, and this could be related to differences in experience, i.e., more experienced player are faster to recognize play-patterns, to anticipate opponent's movements and to react. Results suggested that future study should address more on the individual variety among tennis players to analyze their performance.

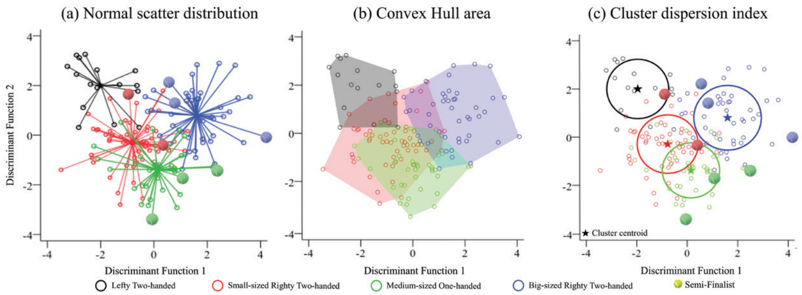


FIGURE 1: The distribution of four player clusters defined by two discriminant functions (featured by normal scatter area, Convex hull area and Cluster dispersion index area).

REFERENCES

Gillet, E., Leroy, D., Thouvarecq, R., and Stein, J. F. (2009). A notational analysis of elite tennis serve and serve-return strategies on slow surface. *J. Strength Cond. Res.* 23, 532–539. doi: 10.1519/JSC.0b013e31818efe29 PMID:19197212

Maquirriain, J., Baglione, R., and Cardey, M. (2016). Male professional tennis players maintain constant serve speed and accuracy over long matches on grass courts. *Eur. J. Sport Sci.* 16, 845–849. doi: 10.1080/17461391.2016.1156163 PMID:26960753

O'Donoghue, P., and Ingram, B. (2001). A notational analysis of elite tennis strategy. *J. Sports Sci.* 19, 107–115. doi: 10.1080/026404101300036299

Talent Development from a Complex Systems Perspective

Ruud J. R. Den Hartigh, Y. Hill, Paul L. C. Van Geert

Faculty of Behavioural and Social Sciences, Department of Psychology, University of Groningen, Groningen, Netherlands

j.r.den.hartigh@rug.nl

Introduction: Research on talent development has mostly attempted to find out how many particular variables, such as practice, physical factors, and psychosocial factors, contribute to the development of elite sports performance (Rees et al., 2016). In line with the complex systems approach, we propose that talent develops out of dynamic interactions among various supporting and inhibiting factors. In our model, talent is considered as a potential in terms of a mathematically defined growth, and ability is the actual level of a variable at a particular moment. The latter is embedded in a set of (changing) interconnected variables, defined as *connected growers*:

$$\left\{\begin{array}{l}\dfrac{\Delta L_A}{\Delta t}=\left(r_{L_A}\,L_A\left(1-\dfrac{L_A}{K_{L_A}}\right)+\sum_{v=1}^{v=i}s_v\,L_A\,V_v\right)\left(1-\dfrac{L_A}{C_A}\right)\\[2ex] \dfrac{\Delta L_B}{\Delta t}=\left(r_{L_B}\,L_B\left(1-\dfrac{L_B}{K_{L_B}}\right)+\sum_{v=1}^{v=j}s_v\,L_B\,V_v\right)\left(1-\dfrac{L_B}{C_B}\right)\\ \qquad\qquad\qquad\cdots\\ \qquad\qquad\qquad\cdots\\ \qquad\qquad\qquad\cdots\end{array}\right\} \tag{1}$$

where $\dfrac{\Delta L_A}{\Delta t}$ corresponds to the change of the variable, K is the stable (genetic) factor, r is the growth rate associated with the stable factor, V corresponds to the other variable components in the network to which the component in question (e.g., L_A) is connected, and s represents the connection weights in the network. The C-parameter corresponds to the carrying capacity of a particular variable (Den Hartigh et al., 2016). The aim of this study was to detect whether our dynamic network model predicts individual developmental trajectories, as well as distributions of major sports achievements across the population. We compared the model predictions with (a) cases of elite athletes, and (b) performance distributions across sports, gender, and scale (world-wide to local). For the sake of space we confine ourselves to Grand Slam victories by female tennis players and goals scored by FC Barcelona players.

Methods: *Model Simulations*: The dynamic network model was implemented in Visual Basic that runs under Microsoft Excel. Table 1 displays the default parameter values that were used.

TABLE 1: Default parameter values.

Parameter	**Average**	**SD**
r (growth rate)	0.05	0.01
s (connection weight)	0	0.02
K (stable resources)	1.00	0.15
Connection probability with other variables	0.25	–
	Minimum	**Maximum**
L (initial level)	0	0.05
Time of initial emergence of a variable	1.00	350.00
C (carrying capacity)	10.00	25.00

We made the model sport-specific by (a) modeling a transition from youth to senior by applying a perturbation around the transition period, and (b) including that athletes may start to generate achievements after the transition, which is a function of their ability, tenacity and chance. Within the 10-node network, we arbitrarily defined node 3 as the ability variable, and node 4 as the tenacity variable. The probability that an achievement is accomplished at some moment, corresponds to:

$$P_t = \varphi \times L_t T_t, \tag{2}$$

where φ is the likelihood parameter, L_t is the ability variable, and T_t is the tenacity variable. Because it is easier to score goals in soccer than it is to win grand slams in tennis, the *φ* parameter had a higher value in soccer (φ = 0.002) than in tennis (φ = 0.0002). Furthermore, because soccer players can score multiple goals in one match, they could generate up to three achievements per time step.

Archival Data: Simulations of the model were compared with the trajectories of grand slam victories by Serena Williams and goals scored for FC Barcelona by Lionel Messi. Furthermore, the distributions of grand slams in women tennis and goals scored by FC Barcelona players were compared with predictions by the model. We included all women who played at least 1 match at a Grand Slam (*n* = 1,274, retrieved from www.itftennis.com, accessed at February 17, 2017) and all players who played at least one match for FC Barcelona (*n* = 585, retrieved from www.laliga.es accessed at February 22, 2017).

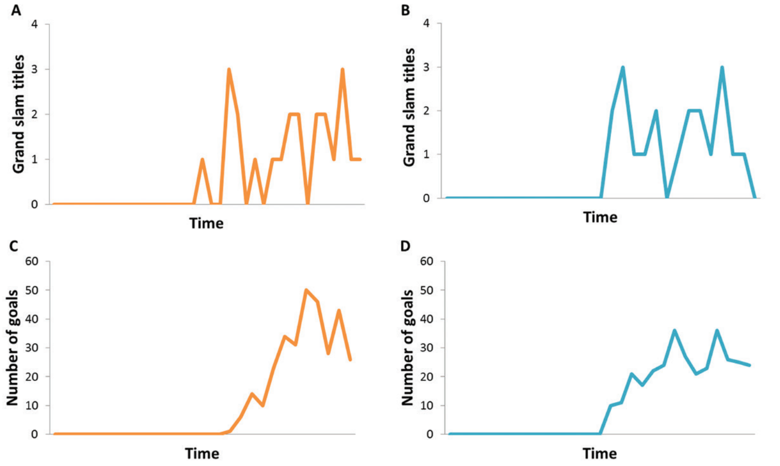


FIGURE 1: Actual (orange) and simulated (blue) trajectories of Serena Williams **(A, B)** and Lionel Messi **(C, D)**.

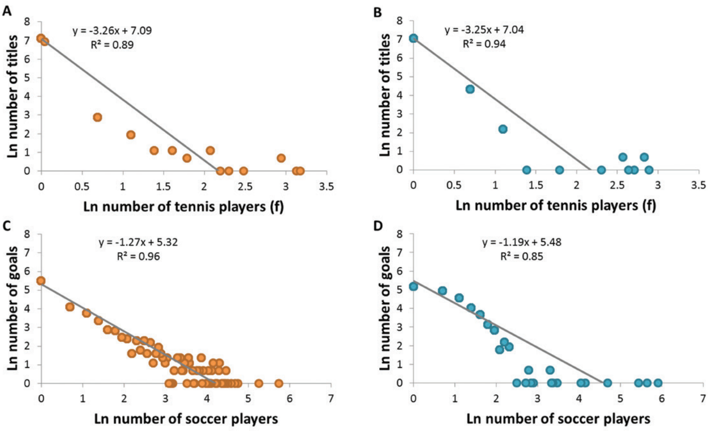


FIGURE 2: Log–log plots for actual (orange) and simulated (blue) performance achievements in women tennis **(A,B)** and male soccer **(C,D)**.

Results: *Individual achievements:* Figure 1 displays the actual (1A) and simulated (1B) trajectories of grand slam victories for Serena Williams. The simulation resulted in a maximum ability level of 20.00, which is 17.74 SDs above the mean ($M_{ability}$ = 1.36, SD = 1.27). The simulated total number of victories was 20, close to Williams' actual number (23). Figures 1C,D display the actual and simulated trajectories of Messi's goals in LaLiga. The simulation yielded a maximum ability of 16.99, with 323 goals in total, close to the actual number (312).

Population distributions: Figure 2 displays highly comparable simulated and actual distributions for women Grand Slam victories (Figures 2A,B) and goals scored by FC Barcelona players in LaLiga (Figures 2C,D). The graphs correspond to log–log plots in which a straight line is indicative of a power law, and the beta-coefficient approximates the power-parameter.

Discussion and conclusion: The dynamic network model provides a framework to understand the theoretical principles underlying the development of talent, and explains empirical observations across sports, gender, and scale. In accordance with a complex systems approach to talent development in sports (e.g., Abbott et al., 2005; Phillips et al., 2010; Den Hartigh et al., 2017), our results suggests that elite sports performance emerges from intra- and inter-individual variations in the composition of individual dynamic networks. It is now time to explore and test the variety of practical applications of the dynamic network perspective.

REFERENCES

Abbott, A., Button, C., Pepping, G. J., and Collins, D. (2005). Unnatural selection: talent identification and development in sport. *Nonlinear Dyn. Psychol. Life Sci.* 9(1), 61–88. PMID:15629068

Den Hartigh, R. J. R., Van Dijk, M. W. G., Steenbeek, H. W., and Van Geert, P. L. C. (2016). A dynamic network model to explain the development of excellent human performance. *Front. Psychol.* 7:532. doi: 10.3389/fpsyg.2016.00532 PMID:27148140

Den Hartigh, R. J. R., Van Yperen, N. W., and Van Geert, P. L. C. (2017). Embedding the psychosocial biographies of Olympic medalists in a (meta-) theoretical model of dynamic networks. *Prog. Brain Res.* 232, 137–140. doi: 10.1016/bs.pbr.2016.11.007 PMID:28648232

Phillips, E., Davids, K., Renshaw, I., and Portus, M. (2010). Expert performance in sport and the dynamics of talent development. *Sports Med.* 40, 271–283. doi: 10.2165/11319430-000000000-00000 PMID:20364873

Rees, T., Hardy, L., Güllich, A., Abernethy, B., Côté, J., Woodman, T., et al. (2016). The great British medalists project: a review of current knowledge on the development of the world's best sporting talent. *Sports Med.* 46, 1041–1058. doi: 10.1007/s40279-016-0476-2 PMID:26842017

Different Familiarity with Running Routes Changes the Complexity of Kinematic and Physiological Responses: A Pilot Study on Recreational Middle-Distance Runners

Juliana Exel[1], Catarina Abrantes[2], Bruno Gonçalves[1], Nuno Mateus[1], Jaime Sampaio[1]

[1]CIDESD, CreativeLab Research Community, Vila Real, Portugal
[2]CIDESD, Geron Research Community, Vila Real, Portugal
juexels@gmail.com

Introduction: Endurance exercises promote positive effects on glucose and lipid metabolism function and reduce the incidence of cardiovascular diseases (Patel et al., 2017). Running can be a popular alternative form of endurance exercise, by the independency on factors, such as age, partners, income, and sportive structure. Monitoring physical activity became popular with the wearable technology and may be a feasible way to monitor physical activity levels. However, the outcome variables provided normally reduce the performance to linear measures, not considering the complex patterns that may be important. The changes that different outdoor environments promote in runners' mechanics and physiology over time (Triguero-Mas et al., 2017), which can be estimated through wearable technology, attain additional meaning about their adaptive capacity. The loss of complexity hypothesis can explain the possibility that running in repetitive and monotonous tracks yields reduction in the dynamic interactions of the complex network of physiological pathways and may lead to reduced point-to-point fluctuations and entropy, suggesting a reduced adaptive capacity for the training effects. It is also all the physiological interactions operating across different time scales that may regulate the adaptations of running in different environmental conditions (Busa and Van Emmerik, 2016). Thus, the aim of the present study was to quantify the amount of complexity associated to the heart rate (HR) of recreational middle-distance runners according to the familiarity of running routes.

Methods: We recruited 3 runners (2 male 42.5±9.5 years old, 170±6.5 cm height, 67.5±2.5 kg weight, 1 female 44 years, 160 cm, 51 kg) that accomplished three 45-min running trials in different scenarios: their usual, unusual, and a standardized 400-m track. They performed the trials during usual training days wearing a GPS and a heart rate belt (SPI-PRO, GPSports, Canberra, ACT, Australia, and Polar Team Sports System, Polar Electro Oy, Finland). We used the middle 20 min of each run for the analysis, and the speed data was smoothed using LOESS function (Cleveland, 1979). There was low regularity in the HR time series, thus, a detrending technique by a third order polynomial was applied. The presence of non-linear features was estimated by difference between the Sample Entropy (SampEn) for both time series and its surrogates, as well as analysing the highest Lyapunov Exponent. We used the IAAFT algorithm for the HR and PPS for the speed (Stergiou, 2016). We applied multiscale entropy (MSE) to quantify the level of regularity and compared across the different scenarios. The reconstruction of the embedding dimension and definition of the time lag (average mutual information) was performed individually.

Results: The mean and deviation values were not compared; however, it does not seem to show any tendency between tracks (Table 1).

TABLE 1: Mean and standard deviations (SDs) of the HR and speed values of experienced runners at usual track, unusual track and 400-m athletics track.

Participant	HR (bpm)						SPEED (m/s)					
	Usual track		Unusual track		400-m track		Usual track		Unusual track		400-m track	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
P1	157.11	5.97	171.2	6.16	165.1	9.70	10.3	1.18	8.65	2.05	9.87	0.58
P2	159.1	0.91	137.82	7.61	160.15	2.06	12.01	0.92	10.57	0.87	12.36	0.60
P3	148.62	4.5	160.58	1.14	161.22	2.05	10.78	1.75	13.8	0.58	13.73	0.78

All the original SampEn values were lower than to the surrogate time series, indicating that the variability found is not only the product of random noise (0.30 vs. 0.47 for usual, 0.63 vs. 0.67 for unusual, and 1.51 vs. 1.54 for the 400-m track). The MSE values for HR showed higher regularity towards higher time scales and is different for P2. The speed MSE values seem to maintain constant regularity as the time scale increases, but tend to separate throughout for P1 (Figure 1).

Discussion and conclusion: The 400-m track was chosen for its monotonous path and landscape. The hypothesis that monotonous and repetitive tracks would present a higher predictability was not confirmed, still, the participants in this study are experienced and rarely use this type of track for training. Thus, the unusual route and the 400-m track can be both considered unusual routes, as evidenced by the P3 in the HR MSE and P2 in the speed MSE. The recruitment of less experienced runners may yield different results. In sum, wearable technology most commonly used for the public to monitor kinematic and physiological status during exercise can help revealing specific non-linear features related to the diversification of tracks that runners choose to practice. This information can be used to monitor the adaptive capacity of practitioners in terms of the inherent effects that physical activity and exercise programs promote.

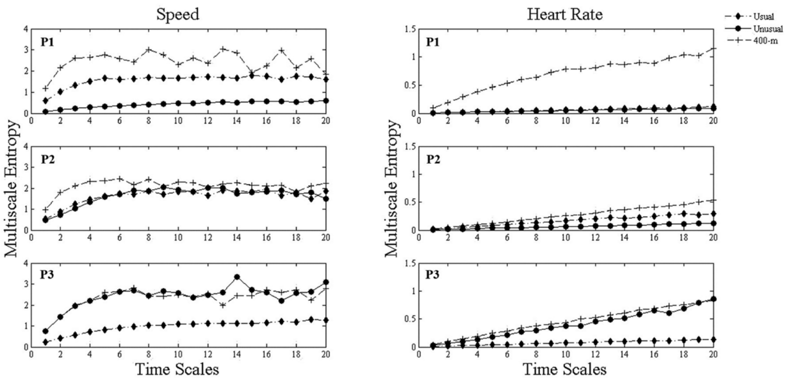


FIGURE 1: Top to bottom: P1, P2, and P3 MSE values for speed (right panel) and HR (left panel) as function of the time scales, at usual track, unusual track, and 400-m athletics track.

REFERENCES

Busa, M. A., and Van Emmerik, R. E. A. (2016). Multiscale entropy: a tool for understanding the complexity of postural control. *J. Sport Health Sci.* 5, 44–51. doi: 10.1016/j.jshs.2016.01.018

Cleveland, W. S. (1979). Robust locally weighted regression and smoothing scatterplots. *J. Am. Stat. Assoc.* 74, 829–836. doi: 10.1080/01621459.1979.10481038

Patel, H., Alkhawam, H., Madanieh, R., Shah, N., Kosmas, C. E., and Vittorio, T. J. (2017). Aerobic vs anaerobic exercise training effects on the cardiovascular system. *World J. Cardiol.* 9, 134–138. doi: 10.4330/wjc.v9.i2.134 PMID:28289526

Stergiou, N. (2016). *Nonlinear Analysis for Human Movement Variability*. Boca Raton: Taylor & Francis.

Triguero-Mas, M., Gidlow, C. J., Martinez, D., De Bont, J., Carrasco-Turigas, G., Martinez-Iniguez, T., et al. (2017). The effect of randomised exposure to different types of natural outdoor environments compared to exposure to an urban environment on people with indications of psychological distress in Catalonia. *PLoS ONE* 12:e0172200. doi: 10.1371/journal.pone.0172200 PMID:28248974

Problem Representation in the Attack Action in Female Volleyball

Carmen Fernández-Echeverría[1], Jara González-Silva[1], Fernando Claver[2], Manuel Conejero[1], M. Perla Moreno[1]

[1]*Faculty of Sport Sciences, University of Extremadura, Badajoz, Spain*
[2]*Faculty of Health Sciences, Miguel de Cervantes European University, Valladolid, Spain*
cafernandeze@unex.es

Introduction: In open sports, with a changing environment, such as volleyball, cognitive skills, and among them the tactical knowledge, acquire fundamental importance (Gil-Arias et al., 2015). Therefore, the objective of this study is to determine the main differences in the problem representation in the attack action of female volleyball players from a team of the Spanish Superleague and players of the National team.

Method: *Participants:* The study sample was composed by the eight attackers of a team of the Spanish Superleague and the eight attackers of the National Absolute Spanish Volleyball Team. *Variables and instruments:* The variable was tactical knowledge, based on the analysis: problem representation, which refers to the knowledge the player uses in order to take a decision in a specific context and game situation 6 × 6 (McPherson and Thomas, 1989).

Coding System: The verbalizations were transcribed and later analysed by means of a category system comprised of three analysis levels (McPherson and Thomas, 1989). (1) Conceptual content was assignment of each concept to a main conceptual category and to a conceptual subcategory (goals, condition, action, regulatory, and "do"). Definitions of main conceptual categories were developed in McPherson and Kernodle (2007). (2) In conceptual sophistication, the quality of the conceptual concepts of goals, condition, and action was assessed (Level 0, Level 1, Level 2, and Level 3). These were established by Moreno et al. (2008), who adapted the current panorama in volleyball. The conceptual sophistication of each condition and action concept was classified by quality of sophistication: Level 0, Level 1, Level 2, and Level 3 (McPherson, 2000; McPherson and Kernodle, 2007). (3) Finally, conceptual structure (single-concept, double-concept, and triple-concept linkages).

Results: The results are differentiated based on three levels of analysis. (1) Concept content: the results show (Table 1) significant differences between the two groups in the total conditions, variety of conditions, total actions, variety of actions, and total regulatory, in favor of the National Team. (2) Concept sophistication: the results show (Table 2) significant differences between the two groups in the goal hierarchies, condition qualities, and actions qualities. (3) Concept structure: there are no significant differences in the concept structure, although there is a greater frequency of double-concept linkages and triple-concept linkages in the National Team.

Conclusion: The players of the National team have a higher level of tactical knowledge, more complex and structured than players of the Superleague team. The comparison of expert profiles provides relevant information that can be considered in the training process (Gil-Arias et al., 2015).

TABLE 1: Means, SDs, and inferential tests in problem representation variables (concept content).

Variables	National Team		Superleague Team		U	Z	Sig.*	ES
	M	SD	M	SD				
Total goals	7.75	5.49	11.00	1.77	15.00	−1.81	0.70	0.45
Variety goals	2.20	1.19	3.00	0.75	20.00	−1.33	0.183	0.33
Total conditions	12.37	3.33	7.50	4.69	13.00	−2.00	0.04	0.50
Variety conditions	7.25	1.90	4.13	2.69	8.50	−2.48	0.01	0.62
Total actions	2.00	1.69	0.50	0.92	14.00	−2.02	0.04	0.50
Variety actions	1.38	1.06	0.25	0.46	12.00	−2.27	0.02	0.56
Total regulatory	7.13	4.70	0.13	0.35	0.50	−3.45	0.00	0.86
Total do	0.13	0.35	0.13	0.35	32.00	0.00	1.00	0.00

*Unilateral significance in the Mann–Whitney *U* test.
ES, effect size = Z/√N.

TABLE 2: Means, SDs, and inferential tests in problem representation variables (concept sophistication).

Variables	National team		Superleague team		U	Z	Sig.*	ES
	M	SD	M	SD				
Goal hierarchies								
0. Skill. themselves	6.13	4.94	0.88	1.72	4.50	−2.94	0.00	0.73
1. Mate. themselves	0.25	0.46	0.13	0.35	28.00	−0.62	0.53	0.15
2. Opponent. themselves	1.13	0.99	7.13	3.27	4.00	−2.98	0.00	0.74
3. Win attributes	0.25	0.46	2.75	2.37	11.00	−2.37	0.01	0.59
Condition qualities								
0. Weak/ inappropriate	0.25	0.46	0.00	0.00	24.00	−1.46	0.14	0.36
1. Appropriate without features	2.38	1.30	0.00	0.00	0.00	−3.60	0.00	0.90
2. Appropriate. one features	7.88	1.88	2.75	1.98	2.00	−3.16	0.00	0.79
3. Appropriate. two or more features	2.00	1.11	4.88	4.22	22.00	−1.08	0.28	0.27
Actions qualities								
0. Weak/ inappropriate	0.00	0.00	0.00	0.00	32.00	0.00	1.00	0
1. Appropriate without features	0.88	1.12	0.00	0.00	16.00	−2.21	0.02	0.55
2. Appropriate. one features	1.13	1.12	0.38	0.74	19.00	−1.51	0.13	0.37
3. Appropriate. two or more features	0.00	0.00	0.14	0.37	24.00	−1.06	0.28	0.26

*Unilateral significance in the Mann–Whitney *U* test.
ES, effect size = Z/√N.

TABLE 3: Means, SDs, and inferential tests in problem representation variables (concept structure).

Variables	National team		Superleague team		U	Z	Sig.*	ES
	M	SD	M	SD				
Singles	2.88	0.83	4.63	2.82	20.00	–1.28	0.19	0.32
Double-concept linkages	4.13	1.24	3.88	2.10	30.00	–0.21	0.83	0.05
Triple-concept linkages	3.00	1.069	2.00	0.28	2.00	–1.07	0.28	0.26

*Unilateral significance in the Mann–Whitney *U* test.
ES, effect size = Z/√N.

Acknowledgements

This work has been developed through the project funded by the foundation Tatiana Pérez de Guzman el Bueno and this work was supported by the Consejería de Economía e Infraestructuras de la Junta de Extremadura (Spain) through the European Regional Development fund.

REFERENCES

Gil-Arias, A., García-González, L., Del Villar, F., Moreno, A., and Moreno, M. P. (2015). Effectiveness of video feedback and interactive questioning in improving tactical knowledge in volleyball. *Percept. Mot. Skills* 121, 635–653. doi: 10.2466/30.PMS.121c23x9

McPherson, S. L. (2000). Expert-novice differences in planning strategies during collegiate singles tennis competition. *J. Sport Exerc. Psychol.* 22, 39–62. doi: 10.1123/jsep.22.1.39

McPherson, S. L., and Kernodle, M. W. (2007). Mapping two new points on the tennis expertise continuum: tactical skills of adult advanced beginners and entry-level professionals during competition. *J. Sports Sci.* 25, 945–959. doi: 10.1080/02640410600908035 PMID:17474048

McPherson, S. L., and Thomas, J. R. (1989). Relation of knowledge and performance in boys' tennis: age and expertise. *J. Exp. Child Psychol.* 48, 190–211. doi: 10.1016/0022-0965(89)90002-7

Moreno, M. P., Moreno, A., Ureña, A., Iglesias, D., and Del Villar, F. (2008). Application of mentoring through reflection in female setters of the Spanish national volleyball team: a case study. *Int. J. Sport Psychol.* 39, 59–76.

Performing Strength Exercises Using a Rotational Inertia Device under Ball Constraint Increases Unpredictability

Bruno Fernández-Valdés[1], Jacob González[2], Julio Tous[3], Jairo Vázquez[2], Jose Gisbert[1], Gerard Moras[1]

[1]National Institute of Physical Education of Catalonia, INEFC, Barcelona, Spain
[2]FC Barcelona, Barcelona, Spain
[3]Chelsea Football Club, Fulham, London
gmoras@gencat.cat

Introduction: Team sports are characterized by high speed running while a ball is carried, passed, kicked, or thrown (Tous-Fajardo et al., 2016). The vast majority of these movements require acceleration and deceleration (Los Arcos et al., 2014). This study aimed to compare the variability of acceleration pattern in professional rugby players, while they performed horizontal forward and backward resistance displacements (HD) with a rotational inertial device (RID) with the same exercise while catching and throwing a rugby ball and performing forward displacements (HDB) using complexity analysis techniques as approximate entropy (ApEn) and traditional accelerometry measures as mean acceleration. ApEn is mathematical algorithm used to quantify the amount of regularity and the unpredictability of fluctuations over time-series data (Pincus, 1991). ApEn quantifies the similarity probability of patterns of length m and $m + 1$. Unlike other previous non-linear methods, ApEn has demonstrated its robustness against noise and its capability to detect complexity changes using finite size datasets, and has provided at least 1,000 data values whenever available (Cuesta-Frau et al., 2017). Conventional approaches to the analysis of human movement have evolved to consider regularity analyse (measurements conducted to assess the variability of a measure) as a possible alternative to the detection of changes in patterns and spatiotemporal characteristics that may improve our understanding of the regularity and complexity of human movement (Murray et al., 2017). Evaluate the variability in non-linear terms is important, because when assessing measures from complex systems such human movement, there are components of the measurement that may appear to be random noise, but actually contain structured non-linear components that can provide insight into the underlying nature of the system (McGregor and Bollt, 2012).

Methods: Twelve professional rugby players (mean ± SD: age 25.6 ± 3.0 years, height 1.82 ± 0.07 m, weight 94.0 ± 9.9 kg). Players performed two series of eight repetitions of HD and HDB at random. In order to avoid confusion variables, execution rhythm and displacement were controlled using a metronome and the same rope length. The RID (Byomedic System SCP, Barcelona, Spain) consists of a metal flywheel (diameter:

0.42 m) with up to 16 weights (0.421 kg and 0.057 m diameter each). The acceleration of the rugby players under both conditions was measured using an inertial measurement unit (WIMU, Realtrack Systems, Almeria, Spain). Data analyses were performed using PASW Statistics 21 (SPSS, Inc., Chicago, IL, USA). The level of statistical significance was set at $p < 05$. The different response variables (mean acceleration and ApEn) were analysed using a repeated measures analysis of variance (ANOVA). The effect sizes (Cohen's *d*) (Cohen, 1992) were also calculated. To separate forward and backward movements they synchronized a video record at 240 fps with the accelerometry signal. Mean acceleration and ApEn were calculated for the module of acceleration signal of overall, forward, and backward movement. The module of acceleration (*at*) was calculated by the expression below:

$$at = \sqrt{z^2 + y^2 + x^2}\,.$$

Results: No mean acceleration differences were found between HM and HMB. There were differences in approximate entropy (ApEn) between HM and HMB in the overall time-series signal ($p = 0.001$) and forward movement ($p = 0.020$), but not backward movement. The effect size for ApEn in the overall and forward displacements was >0.8 (large).

Discussion and conclusion: Traditional strength tasks are too static, since players need to constantly adjust their decisions and actions to change the dynamic performance environments (Travassos et al., 2011). The ball constraint in HMB results in the removal of the critical information sources used by rugby players, highlighting different patterns of movement coordination (Pinder et al., 2011). Entropy was higher for exercise with a rugby ball constraint but no mean acceleration. Complexity analysis techniques can detect changes that are not possible with traditional measures. For these reasons, this algorithm can be used to establish the amount of changes of variability when adding specific contexts constraints in resistance training tasks.

REFERENCES

Cohen, J. (1992). Statistical power analysis. *Curr. Dir. Psychol. Sci.* 1, 98–101. doi: 10.1111/1467-8721.ep10768783

Cuesta-Frau, D., Miró-Martínez, P., Núñez, J. J., Oltra-Crespo, S., and Picó, A. M. (2017). Noisy EEG signals classification based on entropy metrics. Performance assessment using first and second generation statistics. *Comput. Biol. Med.* 87, 141–151. doi: 10.1016/j.compbiomed.2017.05.028 PMID:28595129

Los Arcos, A., Yanci, J., Mendiguchia, J., Salinero, J. J., Brughelli, M., and Castagna, C. (2014). Short-term training effects of vertically and horizontally oriented exercises on neuromuscular performance in professional soccer players. *Int. J. Sports Physiol. Perform* 9, 480–488. doi: 10.1123/ijspp.2013-0063 PMID:23579053

McGregor, S. J., and Bollt, E. (2012). Control entropy: what is it and what does it tell us? *Clin. Kinesiol.* 66

Murray, A. M., Ryu, J. H., Sproule, J., Turner, A. P., Graham-Smith, P., and Cardinale, M. (2017). A pilot study using entropy as a non-invasive assessment of running. *Int. J. Sports Physiol. Perform.* 1–13. doi: 10.1123/ijspp.2016-0205 PMID:28095075

Pincus, S. M. (1991). Approximate entropy as a measure of system complexity. *Proc. Natl. Acad. Sci. U.S.A* 88, 2297–2301. doi: 10.1073/pnas.88.6.2297 PMID:11607165

Pinder, R. A., Davids, K., Renshaw, I., and Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *J. Sport Exerc. Psychol.* 33, 146–155. doi: 10.1123/jsep.33.1.146 PMID:21451175

Tous-Fajardo, J., Gonzalo-Skok, O., Arjol-Serrano, J. L., and Tesch, P. (2016). Enhancing change-of-direction speed in soccer players by functional inertial eccentric overload and vibration training. *Int. J. Sports Physiol. Perform.* 11, 66–73. doi: 10.1123/ijspp.2015-0010 PMID:25942419

Travassos, B., Araújo, D., Vilar, L., and Mcgarry, T. (2011). Human movement science interpersonal coordination and ball dynamics in futsal (indoor football). *Hum. Mov. Sci.* 30, 1245–1259. doi: 10.1016/j.humov.2011.04.003

Cardiorespiratory Coordination: A New Variable for Testing Training and Fatigue Effects

S. Garcia-Retortillo[1,2], C. Javierre[3], R. Hristovski[4], J. L. Ventura[3], P. L. Cerdà[2], E. Coll[2], N. Balagué[1]

[1]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), Universitat de Barcelona (UB), Barcelona, Spain

[2]Complex Systems in Sport Research Group, School of Health and Sport Sciences (EUSES), Universitat de Girona, Salt, Spain

[3]Department Physiological Sciences, Universitat de Barcelona (UB), Barcelona, Spain

[4]Complex Systems in Sport Research Group, Faculty of Physical Education, Sport and Health, Ss Cyril and Methodius University of Skopje, Skopje, Macedonia

nataliabalague@gmail.com

Introduction: Cardiorespiratory exercise testing (CET) is commonly used to evaluate the athletes' aerobic capacity and fitness level. However, its diagnostic and predictive value, in special to assess the changes produced by training and fatigue is limited (Meeusen et al., 2012; Abreu et al., 2016; Balagué et al., 2016). A principal component analysis approach to the time series of cardiorespiratory variables registered during CET has been suggested to assess cardiorespiratory coordination (CRC; Balagué et al., 2016). The authors associate the first principal component (PC_1) with the CRC variable because it accounts for as much of the co-variation as possible among the registered variables. To test the sensitivity of CRC to changes produced by training and fatigue, a set of three experiments addressed to healthy adults were designed. The changes of CRC during CET were respectively studied: (a) before and after a period of 6 weeks of training, (b) in two consecutive CET, and (c) before and after the ventilatory threshold (VT) assessed in each CET.

Methods: A total of 47 participants performed a progressive and maximal cycling exercise (CET), starting at 0 W and increasing the workload at 25 W/min in males and 20 W/min in females, until they could not maintain the prescribed cycling frequency of 70 rpm for more than five consecutive seconds. Maximal oxygen consumption (VO_{2max}), maximal workload (W_{max}), and VT were registered during the test and were compared using a *t*-test. A PCA was performed on the data series of the following selected cardiorespiratory variables, to evaluate the dimensionality of CRC: expired fraction of O_2 (FeO_2), expired fraction of CO_2 ($FeCO_2$), ventilation (VE), systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR). The number of PCs was determined by the Kaiser–Gutmann criterion, which considers PCs with eigenvalues $\lambda \geq 1.00$ as a significant (Jolliffe, 2002). Since the PC_1 always contains the largest proportion of the data variance, eigenvalues of PC_1 were compared between tests by means of a *t*-test.

Results: Main results showed a reduction from 2 PCs to 1 PC after the 6 weeks training period, with no significant differences in VO_{2max}, W_{max}, or VT (Balagué et al., 2016). Conversely, results revealed an increase from 1 PC to 2 PCs and a reduction in eigenvalues of PC_1 ($t = 2.95$; $p = 0.01$; $d = 1.08$), with no significant changes in VO_{2max}, W_{max}, or VT in consecutive maximal exercises (Garcia-Retortillo et al., 2017). Finally, an increase in the number of PCs and a reduction in eigenvalues of PC_1 ($t = 5.54$; $p = 0.001$; $d = 1.22$) was also observed after VT compared to before VT.

Discussion and conclusion: The findings of this set of experiments give consistency to the claim of a high sensitivity of CRC, not only in the evaluation of long-term effects of exercise (training effects; Balagué et al., 2016), but also in the short-term effects of fatigue tested through consecutive maximal exercises (Garcia-Retortillo et al., 2017), and before and after VT. In conclusion, changes in CRC, informing about couplings between cardiorespiratory subsystems, seem more sensitive to changes of training and fatigue than some gold standards such as W_{max}, VO_{2max}, or VT. It then seems reasonable to evaluate CRC together with the commonly registered maximal performance and cardiorespiratory variables to improve the interpretation of CET. These results highlight the value of incorporating complex systems approaches into the current strategic research framework for sport and exercise medicine (Holtzhausen et al., 2014).

REFERENCES

Abreu, P., Mendes, S. V. D., Leal-Cardoso, J. H., and Ceccatto, V. M. (2016). Anaerobic threshold employed on exercise training prescription and performance assessment for laboratory rodents: a short review. *Life Sci.* 151, 1–6. doi: 10.1016/j.lfs.2016.02.016 PMID:26860893

Balagué, N., González, J., Javierre, C., Hristovski, R., Aragonés, D., Álamo, J., et al. (2016). Cardiorespiratory coordination after training and detraining. A principal component analysis approach. *Front. Physiol.* 7:35. doi: 10.3389/fphys.2016.00035

Garcia-Retortillo, S., Javierre, C., Hristovski, R., Ventura, J. L., and Balagué, N. (2017). Cardiorespiratory coordination in repeated maximal exercise. *Front. Physiol.* 8:387. doi: 10.3389/fphys.2017.00387 PMID:28638349

Holtzhausen, L. J., van Zyl, G. J., and Nel, M. M. (2014). Developing a strategic research framework for sport and exercise medicine. *Br. J. Sports Med.* 48, 1120–1126. doi: 10.1136/bjsports-2013-093252 PMID:24652817

Jolliffe, I. (2002). *Principal Component Analysis*. New York, NY: Springer.

Meeusen, R., Duclos, M., Foster, C., Fry, A., Gleeson, M., Nieman, D., et al. (2012). Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med. Sci. Sports Exerc.* 45, 186–205. doi: 10.1249/MSS.0b013e318279a10a

Variability Sliding upon a Novel Slide Vibration Board at Different Vibration Frequencies

Jose Fernando Gisbert Orozco, Bruno Fernández-Valdés Villa, Sergio Rodríguez Jiménez, Gerard Moras Feliu

National Institute of Physical Education of Catalonia (INEFC), University of Barcelona, Barcelona, Spain
gisbertorozcopep@gmail.com

Introduction: Slideboard (SB) exercise is a multifaceted, closed kinetic chain that imparts low-impact forces to the lower extremities, and is used to enhance strength, endurance, proprioception, agility, balance body composition, and cardiorespiratory fitness (Diener, 1994; Weber and Ware, 1998). On the other hand, entropies are among the most popular and promising complexity measures for biological signal analyses (Gao et al., 2012). When considering time series data variables describing agent interactions in social neurobiological systems, measures of regularity can provide a global understanding of such systems behaviours. Approximate Entropy (ApEn) (Pincus, 1991) was introduced as a non-linear measure to assess the complexity of a system behaviour by quantifying the regularity of the generated time series assessing and comparing the regularity of large data series (Fonseca et al., 2012). Acceleration signal used as a non-invasive tool to assess training status and progression (Murray et al., 2016). This study aimed to assess the effect of different vibration frequencies and no vibration on trunk acceleration while sliding upon a novel slide vibration board (SVB) using ApEn analyses. In order to assess regularity, amount, particularly the structure of variability in postural control accompanying a sliding exercise under vibration constrains on trunk acceleration.

Methods: Six amateur skaters (2 males and 4 females; mean ± SD: age 24.9 ± 6.9 years, height 1.72 ± 0.13 m, weight 67.6 ± 27.4 kg) participated in this study. The study was conducted on a 1.80 m SVB (Patent, P201630075). Trunk acceleration of the subjects under different vibration conditions was measured using an inertial measurement unit (WIMU, Realtrack Systems, Almeria, Spain). Root mean square (RMS) and the Approximate Entropy were calculated for the three axis module of acceleration. The study was carried out on 3 days: on the first day, subjects underwent a familiarization session. On the second day, the exercise rhythm for each subject was obtained by metronome. On the third day, each subject performed at their own rhythm controlled by metronome, one set of 30s under the following vibration conditions [no vibration (0), 20, 25, 30, and 35 Hz] at random.

Results: No mean acceleration differences were found between vibration conditions. Significant differences in ApEn were found between 0 Hz and 20 ($p = 0.001$), 25 ($p < 0.001$), 30 ($p < 0.001$), and 35 Hz ($p = 0.001$) (Figure 1).

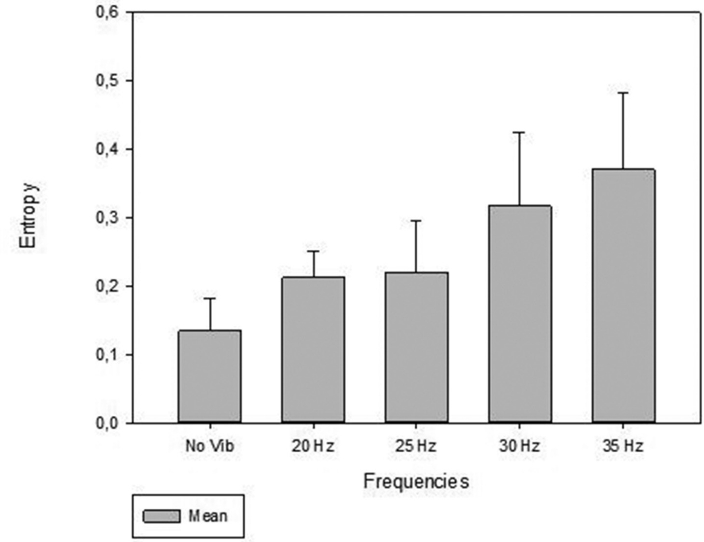


FIGURE 1: Entropy at different vibration frequencies.

Discussion and conclusion: The ApEn values increase with increasing frequency. Sliding on a SVB from 20 to 35 Hz may be considered as a practical alternative to constrain the athlete than sliding without the vibration stimulus and ApEn acceleration signal may be considered as a practical non-invasive alternative to assess vibration constrain.

REFERENCES

Diener, M. (1994). The art, science, and business of the slide. *Fitness Manage.* 10, 26–30.

Fonseca, S., Milho, J., Passos, P., Araujo, D., and Davids, K. (2012). Approximate entropy normalized measures for analyzing social neurobiological systems. *J. Motor Behav.* 44, 179–183. doi: 10.1080/00222895.2012.668233

Gao, J., Hu, J., and Tung, W. (2012). Entropy measures for biological signal analyses. *Nonlinear Dyn.* 68, 431–444. doi: 10.1007/s11071-011-0281-2

Murray, A. M., Ryu, J. H., Sproule, J., Turner, A. P., Graham-Smith, P., and Cardinale, M. (2017). A pilot study using entropy as a non-invasive assessment of running. *Int. J. Sports Physiol. Perform.* 1–13. doi: 10.1123/ijspp.2016-0205 PMID:28095075

Pincus, S. M. (1991). Approximate entropy as a measure of system complexity. *Proc. Natl. Acad. Sci. U.S.A.* 88, 2297–2301. doi: 10.1073/pnas.88.6.2297

Weber, M. D., and Ware, A. N. (1998). "An overview of knee rehabilitation principles," in *Physical Rehabilitation of the Injured Athlete*, 2nd Edn, eds J. R. Andrews, G. L. Harrelson, and K. E. Wilk (Philadelphia, PA: WB Saunders), 362–364.

Exploring How the Position of the Ball Can Affect the Ratio of Effective Playing Space from Confronting Teams in Association Football

Bruno Gonçalves[1], Pedro Marques[2], Carlos Lago-Peñas[3], Juliana Exel Santana[1], Diogo Coutinho[1], Jaime Sampaio[1]

[1]*Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, CreativeLab Research Community, Vila Real, Portugal*
[2]*Football Performance, City Football Services, Manchester, United Kingdom*
[3]*Faculty of Education and Sport, University of Vigo, Pontevedra, Spain*
air.bruno.23@gmail.com

Introduction: Effective playing space (EPS) is defined as the smallest polygonal area delimited by the peripheral outfield players, and contributes to the understanding of how teams use the pitch space to gain superiority over their opponents (Gonçalves et al., 2016). This effectively covered area supposedly relies upon the ball positioning and the interactions between teammates and opponents. Using the EPS of confronting teams, it is possible to calculate the ratio of EPS (rEPS), allowing to quantify pitch space of one team when compared to the opponents. For example, if the rEPS of the team in possession is equal to 1, it means that both teams are covering the same space. For the other side, if the rEPS of the team in possession is equal to 2, this means that the team is covering the double the space of the opponents. Two of the most important issues that probably affect the interpersonal dynamics of both teammates and opponents are the pitch location and ball position. It is likely that the defending team exhibits a more compacted positioning when the ball is in the central zone and near to their target, than when the ball is in the opposite half pitch. Manipulating pitch zones of distinct dimensions can provide different types of information. For example, dividing the pitch into 4 × 4 (length × width) equivalent zones should provide different information in using a 10 × 6 zones pitch. Thus, the aim of this study was to explore how the rEPS varies according to the ball location, using different spacing scales to divide the pitch.

Methods: The sample comprised one match from an elite professional team. The two-dimensional coordinate position of all players and the ball were collected across the entire match using Tracab Optical Tracking®. The analysed team ended the season in the top of the classification table, while the opponent team ended in the bottom. The positional time series from the players were used to compute the following variables: EPS of the team in possession; EPS of the opponent team out of possession; and their ratio (rEPS). The pitch was divided into four space scales: all pitch; macro-division—2 × 2 equal zones; meso-division—4 × 4 equal zones; and micro-division—10 × 6 equal zones. All set pieces of play were excluded from analyses, as well as the balls that were kicked out of the pitch.

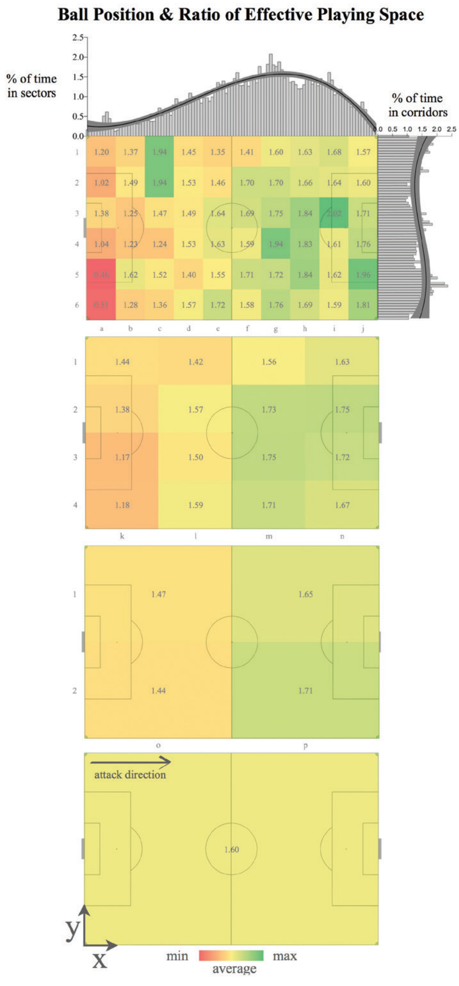


FIGURE 1: Overall representation of the study analysis. The histograms (i and ii) represent the % of time of the ball positioning in bins with 1-m width. Also, a cubic interpolated curve with 99% confidence bands was computed. The pitch square zones show the ratio of effective playing space based on ball position. For instance, the micro-division (upper panel) presented the lower rEPS in the square 5a (rEPS = 0.46, EPS team = 446.55 ± 32.44 m^2 vs EPS opponent = 967.23 ± 7.24 m^2) and higher rEPS in the square 3i (rEPS = 2.02, EPS team = 921.18 ± 166.40 m^2 vs EPS opponent = 499.05 ± 176.6 m^2) while the all pitch (lower panel) presented rEPS = 1.60 (EPS team = 1037.6 ± 258.93 m^2 vs EPS opponent = 703.1 ± 248.6 m^2).

Results: The *x* and *y* coordinates from the ball position within the pitch (for both pitch sector and corridor directions, respectively) were represented in two histograms with bins of 1-m width (see Figure 1). A cubic interpolated curve with 99% confidence bands was computed to better identify where the ball was located most of time (%). The ball was mostly located from the middle to the final third of the pitch. In the corridors, the distribution of ball position was balanced, but presented slightly higher values in right side. The pitch representations in Figure 1 were divided (from the top to the bottom) into micro- (Figure 1, iii) to macro-division (Figure 1, vi) and the rEPS of the analysed team. Different trends could be identified from the visualised scales of the micro-division (Figure 1, iii). For instance, the square 2c and 4g presented the same rEPS (1.94), although there were differences of EPS for each team (2c, EPS team = 1,335.47 ± 346.72 m^2 vs EPS opponent = 733.65 ± 178.26 m^2; 4g, EPS team = 963.72 ± 180.04 m^2 vs EPS opponent = 518.76 ± 149.79 m^2). Also, the % of time that the ball was in both pitch zones was different. The rEPS in the offensive pitch (zone where the ball stayed more time) from the macro-division of the pitch varies from 1.65 to 1.71, while from the micro-division varied from 1.41 to 2.02. Accordingly, the detail of practical information seems to decrease as the scale moves from the micro- towards the macro-division.

Discussion and conclusion: Measuring space occupation on the pitch in relation to the ball position can be of great importance for tactical planning and should be more considered, because it adds noble information to increase the transferability of training tasks to the match. However, coaches and sport analysts should take caution when accounting for the macro-division, as they would miss the critical information for understanding the team's performance; and consequently, players might fail to maintain the same perceptual-motor landscape that they use during competitive settings.

REFERENCE

Gonçalves, B., Marcelino, R., Torres-Ronda, L., Torrents, C., and Sampaio, J. (2016). Effects of emphasising opposition and cooperation on collective movement behaviour during football small-sided games. *J. Sports Sci.* 34, 1346–1354. doi: 10.1080/02640414.2016.1143111 PMID:26928336

Upper-to-Lower Limb Coordination in Front Crawl Swimming: Impacts of Task and Environmental Constraints

Brice Guignard[1], Annie Rouard[2], Didier Chollet[1], Ludovic Seifert[1]

[1]Center for the Study and the Transformation of Physical Activities (CETAPS), Faculty of Sport Sciences, University of Rouen Normandy, Mont Saint Aignan, France

[2]Interuniversity Biology and Motricity Laboratory (LIBM), University Savoie Mont Blanc, Le Bourget du Lac, France

brice.guignard@univ-rouen.fr

Introduction: Front crawl is a particular cyclic task, since it involves combined actions of the upper and lower limbs that are structurally and functionally different (Wannier et al., 2001): 360° arm rotations around the shoulder vs. pendulum leg oscillations. Generally, three main upper-to-lower limb frequency ratios (FR) emerged (Persyn et al., 1983): 1:1, or one stroke cycle of the arm for one leg kick; 1:2, or one arm stroke for two leg kicks, and 1:3, or one arm stroke for three leg kicks. When limbs oscillated with a fixed phase relation and a common coupled frequency, the coordination was called "absolute," whereas a lack of phase and frequency locking was referred to as "relative coordination" (von Holst, 1939). The purpose of this study was therefore to understand the front crawl upper-to-lower coordination dynamics (as a function of speed increase, swimming in a pool vs. a flume). It was first hypothesized that the 1:1 *absolute* FR would lead to the most recurrent upper-to-lower limb coordination pattern. Second, we hypothesized a transition from low FR at slow speeds to 1:3 FR at fast speeds, whatever maybe the environment.

Methods: Eight expert Italian male swimmers (mean ± SD age: 20.8 ± 2.96 years, height: 186.8 ± 3.37 cm, mass: 79.75 ± 7.81 kg) volunteered to participate in this study. Tests took place in a 50 m indoor swimming pool for the first part and in a flume (i.e., water flows against the swimmer) for the second part. Swimmers performed (i) 8 × 50 m bouts in the pool and (ii) forty strokes in the flume each time at 76–80–84–88–92–96–100 and 104% of their mean speed obtained during their best 200 m front crawl. Swimmers wore four inertial sensors with 9 degrees of freedom (Hikob Fox, HIKOB, Villeurbanne, France), positioned on the ventral side of the thighs and the dorsal side of the upper arms. Angles between sensors and the vertical axis were computed using Matlab 2014a software (MathWorks Inc., Natick, MA, USA). Spectral analyses were conducted using fast Fourier transforms (FFT) to extract the peak power frequency of angular time series. Ratio between dominant frequencies of upper arms and thighs were computed for each condition. Friedman's ANOVA was performed on the ranks ($P < 0.05$), using SPSS Statistics (21.0, SPSS Inc., Chicago, IL, USA).

Results: Three FR (obtained over 3,780 stroke cycles) have emerged during the tests: 1:1, 1:2, and 1:3. On average, 1:3 was the most recurrent (64.8 and 57.0% in the pool and flume, respectively), whereas 1:2 was rarely selected by swimmers (3.1 vs. 4.5%). 1:1 was performed most often in the flume than in the pool. FR were on average higher (i.e., 1:3) in the pool for the two fastest swimming speeds on the right body side (Speed 7 with $P = 0.031$ and Speed 8 with $P = 0.016$) and exclusively for Speed 7 on the left body side ($P = 0.031$). It was likewise observed that swimmers switched from low to high FR, but not *vice versa* (Figure 1). The higher the swimming speed in both environments, the larger the recurrence of 1:3. In the pool, FR used to complete the three slowest speeds were statistically lower (i.e., 1:1 or 1:2) than the FR used at Speed 7 or 8 (i.e., 1:3), $P = 0.000$. In the flume, this effect was observed exclusively for the left body side, with a switch from 1:1 to 1:3 ($P = 0.005$).

Discussion and conclusion: As expected, participants exhibited the 1:1, 1:2, and 1:3 upper-to-lower frequency ratios (FR) classically used in swimming (Persyn et al., 1983). These ratios corresponded to the first three levels of the *Farey tree*: stability is inversely proportional to the levels of the ratios in this structure. This point is echoing the demonstration of von Holst (1939) in that two oscillators moving with phase and frequency locking were more stable than relative coordination. 1:1 and 1:3 ratios were

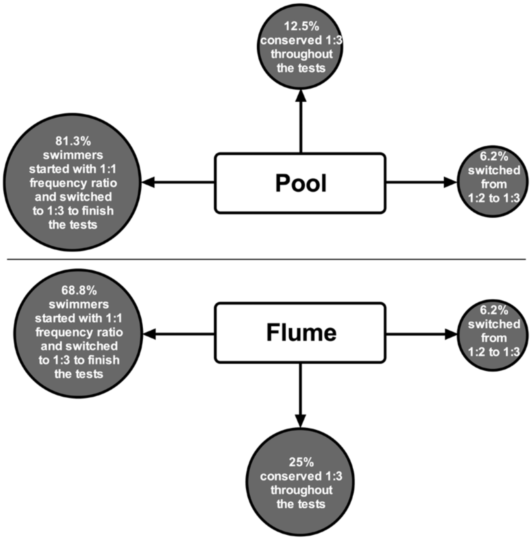


FIGURE 1: Strategies used by swimmers to perform swimming trials with the help of three frequency ratios (1:1, 1:2, and 1:3) as a function of speed increase.

over-represented since 1:1 is mainly involved in the body balance at slow speeds, while 1:3 provides a significant contribution to the propulsion for sprint events (Persyn et al., 1983). 1:3 was the most popular since we can consider that one movement of the legs corresponded to one hand sweep during the underwater sequence. With speed increase, two swimmers' profiles emerged (Osborough et al., 2015): (i) swimmers using a 1:3 FR from the slowest to the fastest speeds and (ii) swimmers beginning at a lower FR, but then switching to 1:3 during the tests. Due to the large amplitude of upper limb movement, cycle duration of the arms commonly superseded that of the legs (Wannier et al., 2001). This is particularly visible at highest speeds, leading to the selection of 1:3 FR. This study will be completed with coupling strength measurements that will explain if the use of 1:3 is a good strategy to swim efficiently.

REFERENCES

Osborough, C., Daly, D., and Payton, C. J. (2015). Effect of swim speed on leg-to-arm coordination in unilateral arm amputee front crawl swimmers. *J. Sports Sci.* 33, 1523–1531. doi: 10.1080/02640414.2014.996181 PMID:25562689

Persyn, U., Daly, D., Vervaecke, H., van Tilborgh, L., and Verhetsel, H. (1983). "Profiles of competitors using different patterns in front crawl events," in *Swimming Science IV*, eds A. P. Hollander, P. A. Huijing, and G. de Groot (Champaign, IL: Human Kinetics), 323–328.

von Holst, E. (1939). Die relative koordination als phänomen und als methode zentralnervöser funktionsanalyse. *Ergeb. Physiol.* 42, 228–306.

Wannier, T., Bastiaanse, C., Colombo, G., and Dietz, V. (2001). Arm to leg coordination in humans during walking, creeping and swimming activities. *Exp. Brain Res.* 141, 375–379. doi: 10.1007/s002210100875 PMID:11715082

Visual-Motor Exploration during Learning: A Case Study in Climbing

Guillaume Hacques[1], Jérôme Bourbousson[2], John Komar[1], Ludovic Seifert[1]

[1]Center for the Study and the Transformation of Physical Activities (CETAPS), Faculty of Sports Sciences, University of Rouen Normandy, UNIROUEN, Mont Saint Aignan, France
[2]"Movement, Interactions, Performance" Laboratory (MIP), Faculty of Sports Sciences, University of Nantes, Nantes, France
guillaume.hacques@univ-rouen.fr

Introduction: In ecological dynamics framework, motor learning is considered as the destabilization of the intrinsic dynamic and stabilization of emergent state. This destabilization occurs through a nonlinear process that often looks like an intermittent regime during which the learner alternates between exploitation of behaviors existing in the intrinsic dynamics and exploration of new behaviors (Chow et al., 2008). Therefore, learning lies in exploring the perceptual-motor workspace, dynamically evolving with the constraints from the organism, the environment and the task (Newell et al., 1991). In climbing, visual-motor exploration consists in acquiring reachability, graspability, and hold useability to move upward. Exploration occurs during the climb and between climbs (i.e., intra- and inter-trial variability). To describe these two levels of exploration, the constraint-led approach enables to test the intrinsic dynamics. For instance, the manipulation of the route design and practice led the climbers to be more attuned to informational variable for action (Seifert et al., 2015). The aim of this study was to understand and explain how learners explored new opportunities for actions in terms of reach-, grasp-, and use-abilities. We hypothesized that the manipulation of environmental constraints could invite learners to perceive opportunities for action.

Methods: The learning protocol consisted of 13 climbing sessions, including a pre-test, post-test, and retention test. The task-goal was to "*find the way to climb the route as fluently as possible, avoiding pauses and saccades*." Our case study focused on the three tests for one learner. The tests were composed of four different routes ("Control," "Usability," "Graspability," and "Reachability") which had the same number of hand-holds (16). Control route was used as basis and the three others differed as follows: (1) Usability route: hand-holds were turned 90° (Seifert et al., 2015); (2) Graspability route: hand-holds shape was changed; and (3) Reachability route: distances between hand-holds were increased. During the practice sessions, participant climbed three times the control route and received fluency scores. On each ascent, climber wore eye tracking glasses and a harness with a light and an inertial sensor placed on the back. Ascents were filmed with two cameras, both capturing the entire route. Eye fixations' location on the wall was obtained with SMI BeGaze eye tracking analysis software. The harness's light was tracked on the videos on Kinovea to acquire the hip coordinates. A notational analysis was performed to get the starting and ending time of contacts between climber's limbs and holds. Data were analyzed on Matlab software to compute the fluency scores (jerk of hip rotation, geometric index of entropy, immobility score, and climbing time) and our behavioral variables (number and rate of performatory/ exploratory fixations -PF/EF-, number of performatory/exploratory movements -PM/ EM-, number of hand/feet PM).

Results: In all routes, the fluency scores decreased in the post- and retention test, but this decrease was more important in the Control route. Fluency scores were lower in the retention test than in the post-test only in the usability route (Figure 1). In the Control route, number of PM and EM decreased after learning. Hand PM were fewer in post- and retention tests, whereas number of feet PM remained constant. Number of PF and EF decreased on post- and retention tests while PF rate increased after learning and the EF rate decreased on post-test but increased on retention test comparing to pre-test. Behavioral variables results revealed a route effect on the climber activity (Figure 2).

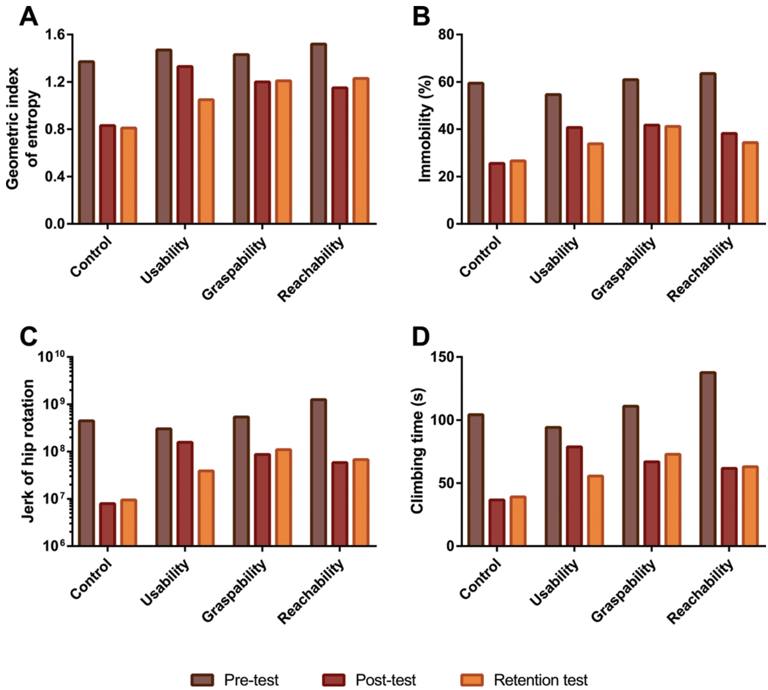


FIGURE 1: Hip trajectory and visual fixations while performing the Control **(A)**, Usability **(B)**, Graspability **(C)**, and Reachability **(D)** routes during the retention test.

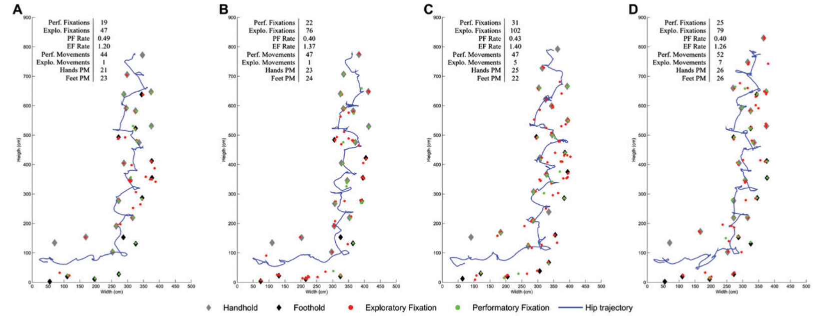


FIGURE 2: Spatial **(A)**, temporal **(B)**, and spatiotemporal **(C)** scores, and climbing time **(D)** in the four routes during the three tests sessions.

Discussion and conclusion: Non-surprisingly, practice showed positive effects on fluency scores; these effects being more significant for the control route (performed during learning) and confirmed by fewer movements and visual fixations. Interestingly, only the Usability route exhibited a better fluency between the post- and retention tests, suggesting that with practice, the climber learnt functional properties of the environment in a sense that he could use more efficiently holds to transit between them. Following the methodology by Nieuwenhuys et al. (2008), our results questioned the relevance of such quantitative analysis to investigate visual-motor exploration. Indeed, this case study showed that a route can be discovered (climbed for the first time) with either a low or a high number of "exploratory" movements and that the number of visual fixations decreased with learning, but this decrease was not obvious when normalized by the climbing time. Moreover, the distinction between "performatory" and "exploratory" behavior suggests that climbers only explored when they were not moving. Another way to examine exploration could be to consider the degree of discovery and novelty trial-to-trial. Perspectives could be to examine the exploration (i.e., pattern emerging and stabilizing from the learning session) versus exploitation (i.e., pattern pre-existing in the repertoire) of visual-motor behavior during a learning protocol.

REFERENCES

Chow, J.-Y., Davids, K., Button, C., and Rein, R. (2008). Dynamics of movement patterning in learning a discrete multiarticular action. *Motor Control* 12, 219–240. doi: 10.1123/mcj.12.3.219 PMID:18698107

Newell, K., McDonald, P., and Kugler, P. (1991). "The perceptual-motor workspace and the acquisition of skill," in *Tutorials in Motor Neuroscience*, eds J. Requin and G. Stelmach (Amsterdam: Kluwer-Academic), 95–108.

Nieuwenhuys, A., Pijpers, J., Oudejans, R., and Bakker, F. (2008). The influence of anxiety on visual attention in climbing. *J. Sport Exerc. Psychol.* 30, 171–185. doi: 10.1123/jsep.30.2.171 PMID:18490789

Seifert, L., Boulanger, J., Orth, D., and Davids, K. (2015). Environmental design shapes perceptual-motor exploration, learning, and transfer in climbing. *Front. Psychol.* 6:1819. doi: 10.3389/fpsyg.2015.01819 PMID:26635707

Complex Learning Theory: Does the Quantity of Exploration during Motor Learning Really Influence the Learning Rate?

John Komar, Ludovic Seifert

Normandie Univ, UNIROUEN, CETAPS, Rouen, France
john.komar@univ-rouen.fr

Introduction: The Complex Learning Theory (Light, 2008) and more generally complex systems perspectives on motor learning emphasize the role of perceptual-motor exploration during learning in order to ensure the acquisition of a highly individualized, adapted, and adaptable movement pattern. Recent researches have shown that stable behaviours will be strong attractors, i.e., that human beings have a strong tendency to exploit already stable patterns rather than looking for new ones even potentially more efficient (Neal et al., 2006). From this perspective, the role of a pedagogical setting refers to putting the learner away of his comfort zone in order to foster the amount of exploration during learning—e.g., non-linear pedagogy (Chow et al., 2011). The objective of this research was to investigate the relationship between the amount of induced exploration during learning and its potential impact on the evolution of the performance. In other words, we followed both the dynamics of the behaviour (i.e., quantifying the exploration) and the dynamics of the performance (i.e., quantifying the rate of improvement).

Methods: For this experiment, 32 beginners in breaststroke swimming were distributed in four groups of learning: (i) *control group* receiving only the goal of the learning, (ii) *analogy group* receiving the goal of learning accompanied by an analogy about "how to perform," (iii) *pacer group* receiving the goal of learning and a metronome continuously pushing them to "perform better," and (iv) *prescription group*, where specific and precise instructions were given to the learner in order to prescribe the "good" or "expert" behaviour. Each learner then followed a learning protocol of 16 sessions with 10×25 m swim per session with the goal of decreasing the stroke frequency for a fixed swimming speed. Both performance (i.e., stroke frequency) and motor behaviour (i.e., arm-leg coordination) were collected. The arm–leg coordination patterns were computed by the continuous relative phase between knee and elbow angles (following Seifert et al., 2010). Afterwards, a cluster analysis was performed on a coordination to get a qualitative label for every cycles performed during the entire process of learning. Eleven coordination patterns were identified by the clustering and were used to calculate an exploration/exploitation ratio. Every time the same pattern was repeated, an *exploitation* behaviour was considered. When the pattern of the next cycle was different than the previous one, an *exploration* behaviour was defined. The exploration/exploitation ratio was therefore calculated for each individual as the number of exploration behaviours observed divided by the number of exploitation behaviours. A Kruskall–Wallis test was used to test the differences between groups. Concerning the performance, the average stroke frequency per session was calculated and the dynamics of the performance was modelled through an exponential curve (Liu et al., 2003). Models followed the form: $stroke\ frequency = a \times exp(-b \times session\ number) + c$. Regarding this fitting, a highest value for the parameter b represents a fastest learning rate. A one-way ANOVA was used to compare the parameter values between groups.

Results: An example of the behavioural dynamics exported after the cluster analysis is presented in Figure 1. Concerning the exploration/exploitation ratio, all groups showed significant differences (*) (Table 1). Only the analogy group showed a significant difference with the other three groups in terms of learning rate, corresponding to a higher value of b ($p < 0.033$) (Figure 2).

Discussion and conclusion: Based on the exploitation/exploration ratio, our results showed that a high-level of constraint did not appear as a mandatory condition to foster the exploration of motor behaviours during learning. In this case, the metronome was supposed to be the most constraining condition as it was continuously imposing a lower frequency. The analogy was merely given at the beginning of the trial and the effectiveness of this instruction was neither imposed nor checked. The analogy seemed to correspond to an optimal compromise between constraining the behaviour to see a transition and allowing time for the learner to appropriate this new (and potentially transitory) behaviour. Those results confirm a previous publication suggesting that there is an optimal degree of fluctuations and most importantly a strong qualitative nature of the exploration (Hossner et al., 2016). In other words, the aim of manipulating the constraints is not only to put the learner away of his comfort zone, but also to provide him relevant information about "where" to explore the perceptual-motor workspace.

TABLE 1: Exploration/exploitation ratio for each learner for the four learning conditions.

	Participants								
Group	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Mean**
Control	0.731	0.678		0.652	0.812	1.015	0.231	0.821	0.706*
Pacer	0.735	0.952	1.084	1.204		0.787	1.477	0.892	1.019*
Analogy	0.71		0.949		0.937	0.815	0.705	0.914	0.838*
Prescription		1.121		1.084	0.76	1.05	1.57	1.239	1.137*

*$p < 0.05$.

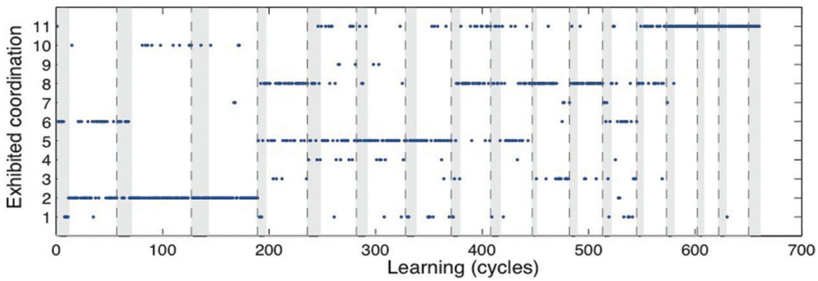


FIGURE 1: Example of the dynamics of learning for a single learner from the analogy group (one point representing one performed cycle).

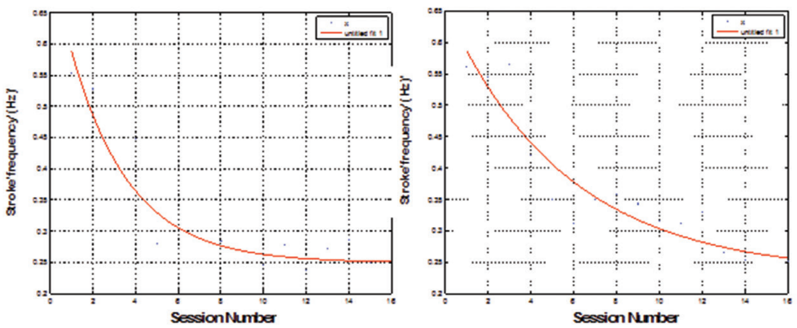


FIGURE 2: Example of two curve fitting representing different learning rates: one learner from the analogy group (left, *b* = 0.359261) and one learner from the control group (right, *b* =0.177742).

REFERENCES

Chow, J.-Y., Davids, K., Hristovsky, R., Araujo, D., and Passos, P. (2011). Non-linear pedagogy: learning design for self-organizing neurobiological systems. *New Ideas Psychol.* 29, 189–200. doi: 10.1016/j.newideapsych.2010.10.001

Hossner, E.-J., Käch, B., and Enz, J. (2016). On the optimal degree of fluctuations in practice for motor learning. *Hum. Mov. Sci.* 47, 231–239. doi: 10.1016/j.humov.2015.06.007 PMID:26123921

Light, R. (2008). Complex learning theory in physical education: an examination of its epistemology and assumptions about how we learn. *J. Teach. Phys. Educ.* 27, 21–37. doi: 10.1123/jtpe.27.1.21

Liu, Y.-T., Mayer-Kress, G., and Newell, K. M. (2003). Beyond curve fitting: a dynamical systems account of exponential learning in a discrete timing task. *J. Mot. Behav.* 35, 197–207. doi: 10.1080/00222890309602133 PMID:12711589

Neal, D. T., Wood, W., and Quinn, J. M. (2006). Habits—a repeat performance. *Curr. Dir. Psychol. Sci.* 15, 198–202. doi: 10.1111/j.1467-8721.2006.00435.x

Seifert, L., Leblanc, L., Chollet, D., and Delignières, D. (2010). Interlimb coordination in swimming: effect of skill level. *Hum. Mov. Sci.* 29, 103–113. doi: 10.1016/j.humov.2009.05.003

Chasing in Biological Systems. A Pedagogical Example for Learning General Dynamical Systems Concepts

Pau Martínez[1], Robert Hristovski[2], Pablo Vázquez[3], Natàlia Balagué[3]

[1]*Faculty of Science, Universitat Autònoma de Barcelona (UAB), Bellaterra, Spain*
[2]*Complex Systems in Sport Research Group, Faculty of Physical Education, Sports and Health, University of Saints Cyril and Methodius, Skopje, Macedonia*
[3]*Complex Systems in Sport Research Group, INEFC University of Barcelona (UB), Barcelona, Spain*
paumartinezbalague@gmail.com

Introduction: There are commonalities among processes occurring at different levels of matter organization: from elementary particles to cells up to social scale and beyond (Hristovski, 2013; Balagué et al., 2017). As shown in Figure 1, short-length and long-length scales, characteristic of elementary particles and líving matter processes, respectively, can be described and understood using general concepts and principles of Dynamical Systems Theory (DST). The objective of this pedagogical example is to show the commonalities of the chasing phenomenon manifested at two different scales. At nanoscale, chasing is presented through the neutrophil–bacteria interaction, and at individual/social scale through the attacker–defender interaction in a team sport (soccer).

Methods: To describe the chasing phenomenon at two different organization levels: nanoscale and individual/social scale using the same general DST concepts.

Results: (a) Chasing at nanoscale: neutrophil–bacteria interaction: neutrophil and bacteria possess membrane receptors by which they sense and *interact* with the environment. When there is no significant concentration of chemo attractants in the environment, the motion of neutrophils may be random and *symmetrically* directed in space, i.e., any direction of motion is possible. However, if the concentration of chemo attractants of the bacteria increases, shortly after it a *symmetry breaking* bifurcation event occurs. The previous state of the neutrophils becomes *unstable* and a new phase starts. Their contractile elements (actin filaments) which were *symmetrically* distributed across the cell become concentrated close to the bacteria. By a positive feedback, the small signal from the receptors engages an increasingly larger set of processes that reorganize the neutrophil. A polarization of the concentration of contractile elements *emerges* as a *collective effect* in the neutrophil's interior. As a result, the neutrophil body *self-organizes* into front and back. The cell obtains its orientation (arrow) of motion. A net *gradient* is formed towards the bacteria (chemotaxis) which extends the *symmetry breaking* from neutrophils interior into the environment at the level of neutrophil–– bacteria system. Bacteria after sensing the neutrophil activates the protein motors in the flagella and moves against the *gradient*. The *gradient* is chemo repellent for it. A *collective* neutrophil–bacteria behavior *emerges*: chasing (see Figure 2, upper panel). The chasing would not happen if both microorganisms were separated and did not *interact*. The chasing *state* is defined by the *gradient* direction and the average distance between the neutrophil and the bacteria. In the chasing phase these *state variables* are *stable* but *fluctuate*. These *fluctuations* are partly produced by the *context* characterized by red cells obstructions that soften the movement of both microorganisms. In this phase, the average neutrophil–bacteria distance *attractor* state is non-zero. When the neutrophil ingests the bacteria this value *transits/bifurcates* to zero and with this transition the cycle ends. The order of the *space scale* of these events is 10^{-6}–10^{-9} m, the distance between the bacteria and the neutrophil, and the *characteristic time* is about seconds. (b) Chasing at individual/social scale: defender–attacker interaction: players possess visual and auditory systems that allow them to *interact* effectively with the environment. When far from the area of activity, soccer players may be in resting state. This state is *symmetric* because no preferred direction of motion exists. However, if the visual context of the environment is changed by the presence of opponents (attackers, ball possessors), shortly after sensing it a *symmetry breaking bifurcation* event occurs. By a positive feedback the visual information engages an increasingly larger set of processes that reorganize the whole organism of the defender creating an intentional *attractor*, that together with the musculo-skeletal system activation provokes the emergence of a goal directed motion. The previous rest (undirected) state

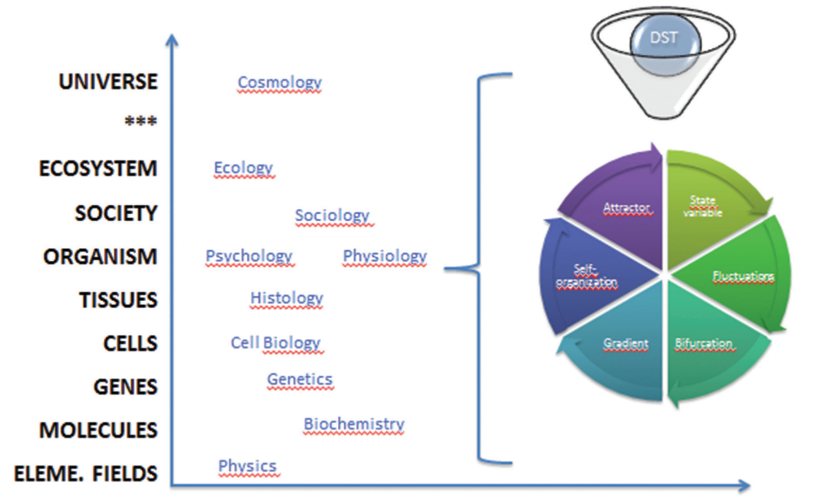


FIGURE 1: Structure and organization of scientific fields sharing the same concepts and principles from Dynamical Systems Theory.

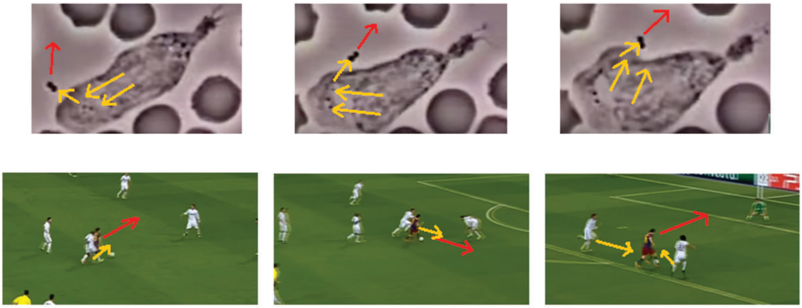


FIGURE 2: Upper panel: chasing at nanoscale (neutrophil–bacteria) interaction. Lower panel: chasing at individual/social scale (attacker–defender interaction). Red arrows show the direction of bacteria and attacker. Yellow arrows show the direction of neutrophil and defender. The neutrophil–bacteria and attacker–defender systems self-organize into a preferred direction through a symmetry breaking process.

of the defender becomes *unstable* and a new phase starts. His neuro-musculo-skeletal system, which was initially at rest, starts interacting and orienting the motion towards the attacker player. A net *gradient* is formed towards the attacker which extends the *symmetry breaking* from the neuro-musculo-skeletal structures into the environment at the level of attacker–defender system. The attacker, after sensing the defender, activates its contractile units and moves against the *gradient*. The *gradient* is repellent for it. A *collective* attacker–defender behavior *emerges*: chasing (see Figure 2, lower panel). The chasing would not happen if both players were separated and did not *interact*. The chasing *state* is defined by the *gradient* direction and the average distance between the players. In the chasing phase these *state variables* are temporarily *stable (metastable)* but *fluctuate*. These *fluctuations* are partly produced by the environmental *context* formed by other team mates that soften the movement of both players. The average attacker–defender distance *attractor* state is non-zero. At the moment when the attacker scores a point this value sharply *bifurcates* to some other value. The attacker–defender system *destabilizes* and dissolves. With this transition the chasing phase ends. The order of the *space scale* of these events is meters, the distance between the players, and the *characteristic time* is about seconds.

Conclusion: An attempt was made to illustrate how general DST concepts and principles describe the chasing phenomenon occurring at different organization levels (from hundreds of nanometers to tens of meters). Movement analogies from sport can be used for educational purposes: (a) to provide an embodied experience in learning general DST concepts and principles and (b) to show how this set of concepts and principles contribute to the transfer of knowledge and to the development of synthetic/integrated scientific understanding.

REFERENCES

Balagué, N., Torrents, C., Hristovski, R., and Kelso, J. A. S. (2017). Sport science integration: an evolutionary synthesis. *Eur. J. Sports Sci.* 17, 51–62. doi: 10.1080/17461391.2016.1198422 PMID:27685425

Hristovski, R. (2013). Synthetic thinking in (sports) science: the self-organization of the scientific language. *Res. Phys. Educ. Sport Health* 2, 27–34.

The Relevance of Game and Context Variables in Futsal Goals Scored in Attack with Goalkeeper As an Outfield Player

César Méndez Domínguez, Jesús Moral Rodriguez, Miguel Gómez Ruano, Luis Miguel Rúiz, Yixiong Cui

Faculty of Science of Physical Activity and Sport, Technical University, Madrid, Spain
cesarmendez4@yahoo.es

Introduction: The goalkeeper as an outfield player is a tactical procedure that allows the goalkeeper to act as an advanced player, helping the attacking team to have a numerical advantage. It is being frequently implemented in futsal, usually when a team faces an adverse scoreboard in the final moments of the match, which is commonly called Critical Moment (Ferreira and Volossovitch, 2013). In addition, the presence of variables such as match location and opponent's effect can enhance or minimize the effects of a "critical" scenario and ultimately influence the success in performance (Lago-Ballesteros et al., 2012). However, little has been studied concerning its theoretical advantage and whether it is conditioned by the context variables (Vicente-Vila and Lago-Peñas, 2016), or effectiveness in real match situation (Newton-Ribeiro, 2011). Some authors have characterized the effectiveness of this procedure in relation to the game variables, focusing on the importance of the space, number of passes, and players as main indicators of effectiveness in attack (Lapresa et al., 2013; Gómez et al., 2015). The coaches still feel doubtful about making decision to use this tactic; therefore, the objective of this study was to see to which extent the goals achieved through the attack with goalkeeper as an outfield player have a pattern related with the variables of the game and of the context.

Methods: In this study, 582 goals made in attack with goalkeeper as an outfield player were collected from a total of 1,325 matches within five complete seasons (2010–2015). A two-step cluster analysis was performed to explore and classify the goals in relation to two models: one was related to four game variables, which included finishing zone (10–20 m, right side, left side, area), number of passes (1–10, 11–36), shot type (1 × 1, outside shot, second post shot), number of players (1–5); and another was related to three contextual variables: match status (losing, tying, and winning), quality opposition (best against worse, 5v4 between equals, worse against better), and match location (home, away).

Results: The results reported that both models, related to the game and the context, were good in clustering quality (see Figure 1). Concerning the context variables, the variable of greater weight was quality opposition. The characteristics of the two most important groups were (1) 31.4% of the goals made in the attack with goalkeeper as an outfield player was obtained when similar level teams contested (100%), losing (100%), and playing away (100%). They were called goals in hostile environment. (2) 23.9% of the goals made when this tactic was carried out between similar level teams (100%), losing (90%), and playing at home (85%). They were attributed as goals in friendly environment. In respect of the game variables, the variable of greater weight was the number of passes. The characteristics of the two most important groups were (1) 48.8% of the sample is the goal made when teams played with a sequence of 1–10 passes (100%), kicking in the area (100%) with 1 × 1 action (61.1%), and the participation of five (41.4%). This goal was called precision goal. (2) 32.1% of the sampled goals was the one obtained when teams played with a sequence of 1–10 passes (100%), ending in the right zone (35.3%), with outside shot (51.1%), and with four players (44%). This goal was named surprise goals (see Figure 2).

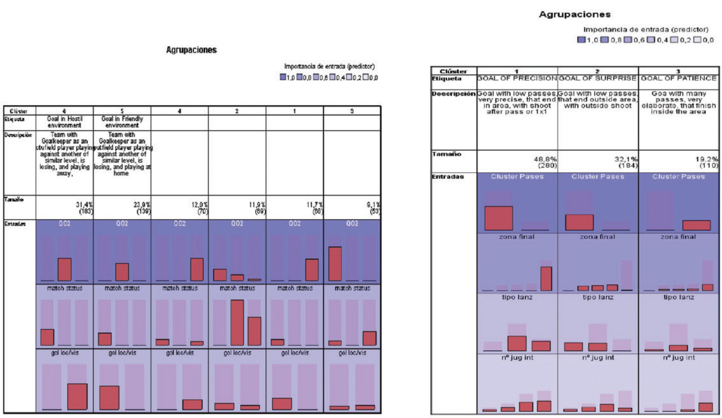


FIGURE 1: Cluster related to the context (left) and to the game (right).

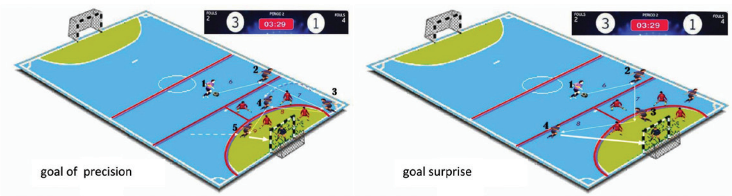


FIGURE 2: Graphical scheme of goal precision and goal surprise.

Discussion and conclusion: On the critical context, the results reflect the less importance of match status and match location. This situation was expected because the tactic of attacking with goalkeeper as an outfield player was justified by the teams that are losing and try to recovery the state of equilibrium (Newton-Ribeiro, 2011). This was in line with the study of Vicente-Vila and Lago-Peñas (2016) that speculated an unexpected non-significant influence of match location and match status on the effectiveness probability in ball possession. By contrast, the quality of opposition seemed to be the most important contextual factor that could influence the success of the goal. Therefore, if the majority of the actions corresponding to teams of similar ranking, the differentiating factor of effectiveness will be put by the highest level teams. In relation to the game, the two most important factors are the number of passes and the final zone. This seemed to be consistent with the goalkeeper as an outfield player, who has to be integrated with a quick ball mobility to strike the defense, and this numerical superiority would facilitate the teams to get closer to the area. This agreed with the previous studies that the greater success of the ball possession was related to the smaller number of passes realized and shots in penalty area (Lapresa et al., 2013, Vicente-Vila and Lago-Peñas, 2016).

REFERENCES

Ferreira, A., and Volossovitch, A. (2013). "Criticalidad e momentos críticos nos jogos desportivos: Una revição teórica," in *Fundamentos e aplicações em análise do jogo*, 1ª Edn, eds A. Volossovitch and A. Ferreira (Lisbon: Edições FMH), 35–60.

Gómez, M., Moral, J., and Lago-Peñas, C. (2015). Multivariate analysis of ball possessions effectiveness in elite futsal. *J. Sports Sci.* 33, 2173–2181. doi: 10.1080/02640414.2015.1075168 PMID:26280547

Lago-Ballesteros, J., Lago-Peñas, C., Rey, E., Martínez, L., and Domínguez, E. (2012). El éxito ofensivo en el fútbol de élite: influencia de los modelos tácticos empleados y de las variables situacionales. *Euro. J. Hum. Move.* 28, 145–170.

Lapresa, D., Álvarez, L., Arana, J., Garzón, B., and Caballero, V. (2013). Observational analysis of the offensive sequences that ended in a shot by the winning team of the 2010 UEFA Futsal Championship. *J. Sports Sci.* 31, 1731–1739. doi: 10.1080/02640414.2013.803584 PMID:23734781

Newton-Ribeiro, F. (2011). A influência do goleiro linha no resultado do jogo de futsal. *RBFF-Rev. Brasileira Futsal e Futebol* 3, 187–198.

Vicente-Vila, P., and Lago-Peñas, C. (2016). The goalkeeper influence on ball possession effectiveness in futsal. *J. Hum. Kinet.* 51, 217–224. doi: 10.1515/hukin-2015-0185 PMID:28149385

Exploring the Effects of a Game-Centred Learning Program on Team Passing Patterns during Youth Football Matches

Bruno N. Pasquarelli, Bruno Gonçalves, Sara Santos, Jaime Sampaio

Research Center in Sports Sciences, Health Sciences and Human Development (CIDESD), CreativeLab Research Community, Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal
brunopasquarelli@hotmail.com

Introduction: The game-centred approaches have been recognized by coaching literature as a more meaningful way to teach sports techniques during early ages, since nurture skill outcomes within game play linking the response execution (Harvey and Jarret, 2014). In this sense, during the game situations, the passing interaction emerges as the first bound of cooperation that children discover while they play football and allows them to progressively build up more sustained offensive behaviours. Further, the passing analysis consists in an important performance indicator in youth football. The creation of passing network has been pointed out as reliable method to assess the passing interactions in youth soccer players (Goncalves et al., 2017). As so, it is possible that the passing relation may be modified as consequence of the training process; however, no study has addressed this issue. Therefore, the aim of this study was to explore the effects of a game-based learning program on team passing patterns during under 11 (U11) football matches.

Methods: The first 6 months of a pedagogical process were investigated in this study. Fourteen players, with 10.2 ± 0.6 years old average, previous experience in training programs, underwent 36 training sessions (14 out of 36 were in the competitive period) with a duration of 90 min, approximately, sustained on modified games, according to the tactical principles (Costa et al., 2009; Renshaw et al., 2010; Pasquarelli, 2017). Six official matches were recorded during this period. The in-game considered variables (using Skout 2.0) were: numbers of successful and unsuccessful passes, passing efficiency (percentage of successful passes), total passing actions and clearance (i.e., when players kick the ball without intention of communication with their teammates). Besides, to assess the intra-team interaction, the edge betweenness centrality and closeness centrality scores (players acting as a bridge among teammates; and, players who connect with more teammates in fewer passes, respectively) were calculated for each player (using Cytoscape1 v3.5.0-RC1) (Shannon et al., 2003; Goncalves et al., 2017). Magnitude-based inferences and precision of estimation were employed in data analysis (Hopkins et al., 2009). The data were presented by the difference in means (%); ±90% of confidence limits.

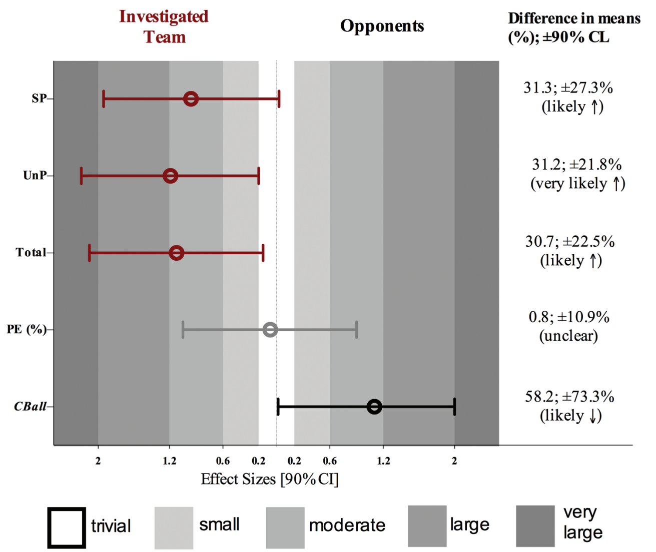


FIGURE 1: Differences in group means in standardized (Cohen) units. SP, successful passes; UnP, unsuccessful passes; Total, total passes; PE (%), passing efficiency; CBall, clearance ball.

Results: The passing actions in the investigated team were higher when compared with the opponents (Figure 1): 31.3; ±27.3% higher in successful passes; 31.2; ±21.8% higher in unsuccessful passes; 30.7; ±22.5% higher in total passes. Besides, higher clearance was found for the opponent (58.2; ±73.3%). No difference was found between teams on passing efficiency. The intra-team assessment, using the social network analysis, showed that the right-back presented the higher edge betweenness centrality index in four of the six matches. The right midfield players showed the highest closeness centrality index in four of the six matches as well. Left centre forward and goalkeeper had the lowest edge betweenness centrality and closeness centrality index, respectively. Figure 2 shows an example of data visualisation from networks analyses from third match.

Discussion and conclusion: The findings of this study may indicate a positive influence of game-centred approach on youth passing interaction patterns. While no differences were found in passing efficiency among teams, the players attempted more than their opponents. Additionally, the lower number of clearance actions was an indicator of the offensive behaviour since it showed that players sought for teammates' support in passing relation. The intra-team analyses were capable to discriminate the players that contributed

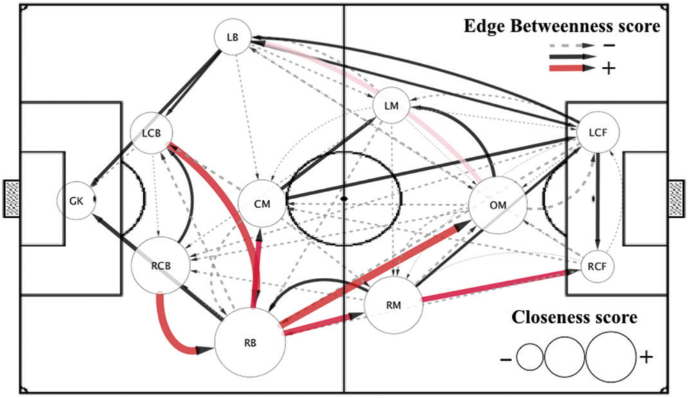


FIGURE 2: Visual representation from U11 match analysis. Players' Positions: GK, goalkeeper; RCB, right centre-back; LCB, left centre-back; RB, right-back; LB, left-back; CM, centre midfield; RM, right midfield; LM, left midfield; OM, offensive midfield; RCF, right centre forward; LCF, left centre forward.

more for the possession and progression of the team game. In conclusion, it may be argued that the game-centred learning program can determinate the playing style features of a U11 football team. Additionally, the social network analysis showed the specific roles of players within game construction and, according to these metrics, the characteristics of each player can be differentiated. Hence, in a long-term assessment, these analyses can offer relevant information about the learning process of the playing model.

REFERENCES

Costa, I. T., Garganta, J., Greco, P. J., and Mesquita, I. (2009). Princípios Táticos do Jogo de Futebol: conceitos e aplicação. *Revista Motriz* 15(3), 657–668.

Goncalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jimenez, S., and Sampaio, J. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS ONE* 12:e0171156. doi: 10.1371/journal.pone.0171156 PMID:28141823

Harvey, S., and Jarret, K. (2014). A review of the game-centred approaches to teaching and coaching literature since 2006. *Phys. Educ. Sport Pedagogy* 19, 278–300. doi: 10.1080/17408989.2012.754005

Hopkins, W. G., Marshall, S. W., Batterham, A. M., and Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Med. Sci. Sport Exercise* 41, 3–12. doi: 10.1249/Mss.0b013e31818cb278

Pasquarelli, B. N. (2017). *Pedagogical Process of a Training Methodology Centered on Game and the Characterization of Passing Interactions of Football Teams in U11 Games (doctorate)*. Campinas, SP: State University of Campinas.

Renshaw, I., Chow, J. Y., Davids, K., and Hammond, J. (2010). A constraints-led perspective to understanding skill acquisition and game play: A basis for integration of motor learning theory and physical education praxis? *Phys. Educ. Sport Pedagogy* 15, 117–137. doi: 10.1080/17408980902791586

Shannon, P., Markiel, A., Ozier, O., Baliga, N. S., Wang, J. T., Ramage, D., et al. (2003). Cytoscape: a software environment for integrated models of biomolecular interaction networks. *Genome Res.* 13, 2498–2504. doi: 10.1101/gr.1239303 PMID:14597658

Network Properties of Successful Performance of Soccer Teams in the UEFA Champions League

Tiago Jorge Pina, Ana Paulo, Duarte Araújo

CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, Lisboa, Portugal
tiagopina13@gmail.com

Introduction: In team sports performance (e.g., association football), individual players in a successful team act as a coherent unit, thus creating a team synergy (Araújo and Davids, 2016) whose properties can be captured by Social Network Analysis (SNA) (Pena and Touchette, 2012). The analysis of ball-passing network suggests that high density (Clemente et al., 2015) and low centralization (Grund, 2012) are associated with successful teams. However, the relation between clustering coefficients and team performance is uncertain (Pena and Touchette, 2012; Gudmundsson and Horton, 2016). Therefore, oversimplification needs to be avoided, since ball-passing network analysis offers an overall picture of events occurring during a certain period of time, where events leading to both successful and unsuccessful performance are included in the same analyses. Thus, it is unclear whether specific network properties and successful team behavior are associated. In this study, we investigated whether density, clustering coefficient, and centralization can predict successful team performance.

Methods: We analyzed 12 games of the Group C of 2015/2016 UEFA Champions League by using public records from TV broadcasts. We started by categorizing all offensive plays (OPs) as *successful* when the attacking team entered the *finishing zone (FZ)*. The concept of FZ was based on previous Gréhaigne et al.'s longitudinal division of the football field (Gréhaigne et al., 2001). *Successful offensive plays* (SOPs) include OPs that finished with a shot at the goal and those where the team retained ball possession until entering the FZ. *Unsuccessful offensive plays* (UOPs) were all the OPs where the team lost ball possession without meeting either of the SOP criteria. *Neutral plays* were OPs where a team did not lose ball possession but also did not meet the SOP criteria, and were not included in the analysis. After collecting data on the ball-passing networks, the network metrics were computed. A hierarchical logistic-regression model was used to predict the successfulness of the OPs from density, clustering coefficient and centralization. We introduced the predictor *total (number of) passes* and the three network metrics in the first and second block, respectively.

Results: Results show that, despite both blocks performed significantly better than a constant-only model (1st block: $G^2_{(1,\ N=283)} = 7.484,\ p = 0.006$; 2nd block: $G^2_{(1,\ N=283)} = 15.484,\ p = 0.004$), only 2nd block satisfied goodness-of-fit criteria (Hosmer and Lemeshow test: 1st block, $\chi^2_{(8,\ N=283)} = 25.342,\ p = 0.001$; 2nd block,

$\chi^2_{(8,\ N=283)} = 7.187; p = 0.517$). Moreover, 2nd block produced a higher Nagelkerke r^2 (1st block: $r^2 = 0.035$; 2nd block: $r^2 = 0.071$) and a higher overall correct classification (1st block: 56.2%; 2nd block 58.7%), Total passes and density were significant predictors. Significantly, a 10% decrease in density increased the chances for a SOP by 73.3% (Exp (β) = 0.267). Furthermore, for density values ranging from 0 to 0.25 there is a similar relation between total passes and number of either SOPs or UOPs (Figure 1), despite the higher frequency of UOPs (Figure 2). However, for density values above 0.25, we see a tendency for a decrease in both SOPs and UOPs, but a predominant occurrence of SOPs.

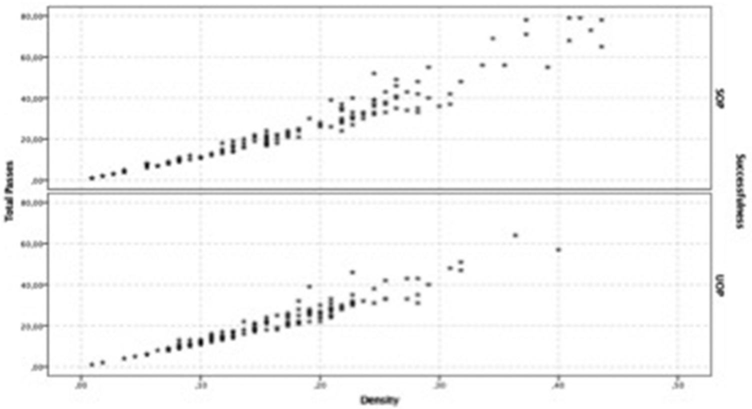


FIGURE 1: Depiction case-by-case of the relationship between density and total passes, for SOP and UOP predicted outcomes, according to the second-block logistic regression model.

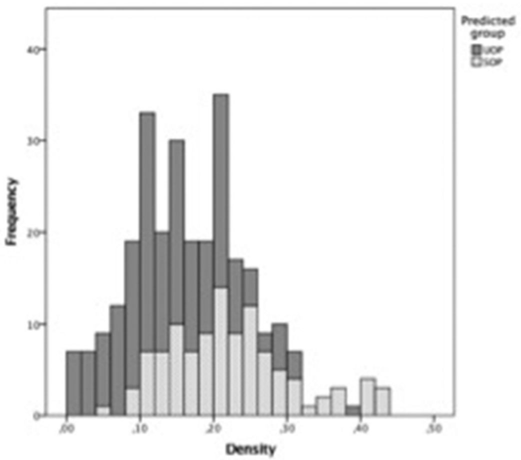


FIGURE 2: Frequencies of density values, according to the category of OP's successfulness.

Conclusion: Results suggest that density contributes to predict a team's ability to enter in the FZ or to shoot at the goal in elite football matches. On the other hand, neither clustering coefficient nor centralization are significant predictors of team performance successfulness. Furthermore, this study gives new insights into the association between density and team performance (Balkundi and Harrison, 2006): (a) low density may be associated with a higher overall number of OPs which are mostly unsuccessful; (b) high density was associated with fewer and/or longer OPs, hence decreasing total SOPs; (c) high density may be associated with fewer ball-possession losses before the teams reach the FZ (hence increasing probability of SOPs), thereby supporting the density-performance hypothesis. The establishment of varied links by a team (high density) is eventually dependent on the creation of numerous lines of pass. In light with ecological dynamics (Araújo et al., 2017), it might be enhanced in training by the manipulation of task constraints, such as: (i) different relationships between depth/width of field; (ii) possession games with numerous mini-goals dispersed in the field; (iii) games with variation of the relationship between the number of players and the playing area. In contrast, for teams that aim to be offensively successful with more constant links (less density), some useful task constraints might be: (i) time limit for the performance of OPs; (ii) small-sided games with few players (1×1, 2×2, 3×3); (iii) improving relationships between specific players by placing such players in the same team in small-sided games or in the training of specific collective actions among them.

REFERENCES

Araújo, D., and Davids, K. (2016). Team synergies in sport: theory and measures. *Front. Psychol.* 7:1449. doi: 10.3389/fpsyg.2016.01449 PMID:27708609

Araújo, D., Hristovski, R., Seifert, L., Carvalho, J., and Davids, K. (2017). Ecological cognition: expert decision-making behaviour in sport. *Int. Rev. Sport Exerc. Psychol.* 1–25. doi: 10.1080/1750984X.2017.1349826

Balkundi, P., and Harrison, D. A. (2006). Ties, leaders, and time in teams: Strong inference about network structure's effects on team viability and performance. *Acad. Manage. J.* 49, 49–68. doi: 10.5465/AMJ.2006.20785500

Clemente, F. M., Martins, F. M. L., Kalamaras, D., Wong, D. P., and Mendes, R. S. (2015). General network analysis of national soccer teams in FIFA World Cup 2014. *Int. J. Perform. Anal. Sport* 15(1), 80–96.

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

Grund, T. U. (2012). Network structure and team performance: the case of English Premier League soccer teams. *Soc. Networks* 34, 682–690. doi: 10.1016/j.socnet.2012.08.004

Gudmundsson, J., and Horton, M. (2016). Spatio-temporal analysis of team sports – a survey. arXiv preprint arXiv:1602.06994. doi: 10.1145/3054132

Pena, J. L., and Touchette, H. (2012). "A network theory analysis of football strategies," in *Sports Physics: Proc. 2012 Euromech Physics of Sports Conference*, ed. C. Clanet, p. 517–528. arXiv preprint arXiv:1206.6904.

Analysis of Decision-Making and Execution Variables in Futsal after an Intervention Program Based on NLP

David Pizarro[1], Fernando Del Villar[2], Alba Práxedes[1], Alberto Moreno[1]

[1]*Faculty of Sport Sciences, University of Extremadura, Cáceres, Spain*
[2]*Field Physical Education and Sport, Rey Juan Carlos University, Madrid, Spain*
davidpizarromateo@gmail.com

Introduction: Futsal is a collaboration-opposition sport, where there is a constant uncertainty in the game environment where players develop decision-making processes (García-González et al., 2009). In this regard, and in terms of ecological dynamics, the tactical behavior of a player is based on intentional adaptations to the conditions imposed in a specific game situation or during the performance of a specific task (Travassos et al., 2012). In this sense, "Small-Sided and Conditioned Games (SSCG)" are suggested as an effective methodological tool to optimize the tactical behavior of athletes (Davids et al., 2013a,b). These games are within the framework of "Non-Linear Pedagogy (NLP)" (Davids et al., 2013a,b), which establishes that in oppositional cooperation sports, the game action arises as a consequence of the interaction of the conditioners of the task and the player, who try to simplify the game situation to guide players to achieve the objectives of the task (Araújo and Davids, 2009). On the other hand, the questioning can be integrated in the conditions of the practice to reach a better adaptation on the players. In this sense, it is considered as a tool whose main purpose is to ask the learner questions that allow him to explore new ways of interacting with the environment and to be able to perform a technical-tactical skill, effectively (Díaz-Cueto et al., 2012). Therefore, the main objective of this study was to analyze the effect of a training program based on NLP, which combines the use of modified games (games that take place in tight spaces, involving small numbers of players and with modified rules of the game) and questioning, in young players of futsal.

Method: The participants were 8 footballers (category Under-16), with ages between 14 and 16 years old and with an experience in federated futsal of 3 years. The independent variable was the intervention program, composed of 12 training sessions from the perspective of Non-linear Pedagogy (NLP). Each training session was structured in four tasks, specifically in four modified games of 15 min each one. It is important to point out that each task was focused on a tactical offensive principle: maintaining possession of the ball (1A), progression towards the opposing goal (2A) and finding the end situation (3A). Finally, the decision-making and execution, in the pass and dribbling actions, were analyzed through the GPET instrument (García-López et al., 2013).

Results: To compare both measures it developed a T-test for relates samples. With respect to the decision-making, results show significant differences between the two measures in both actions (pass, $p = 0.001$; dribbling, $p < 0.001$) being these values higher after the intervention phase. However, with respect to the execution variable, no significant differences were found in any of the actions studied (pass, $p = 0.096$; dribbling, $p < 0.084$).

Discussion and conclusion: According to the results, we can point out that this program, based on the NLP has been proved to be effective to achieve an improvement in decision-making, but not in the execution of the technical-tactical skills (Davids et al., 2005). On the other hand, the application of the questioning has probably had a decisive influence on the results and its usefulness as a tool to improve decision-making can be confirmed (Gil-Arias et al., 2015). On the other hand, these results seem to indicate that it is necessary that the duration of the training program is longer, as determined by previous studies indicating the need for programs to include more than 12 sessions (Harvey et al., 2010).

Acknowledgements

This work was supported by the Ministry of Employment, Enterprise and Innovation of the Government of Extremadura (Spain) through the European Regional Development funds.

REFERENCES

Araújo, D., and Davids, K. (2009). Ecological approaches to cognition and action in sport and exercise: ask not only what you do, but where you do it. *Int. J. of Sport Psychol.* 40, 5–37.

Davids, K., Araújo, D., Correia, V., and Vilar, L. (2013a). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exerc. Sport Sci. Rev.* 41, 154–161. doi: 10.1097/JES.0b013e318292f3ec PMID:23558693

Davids, K., Araújo, D., Vilar, L., Renshaw, I., and Pinder, R. (2013b). An ecological dynamics approach to skill acquisition: implications for development of talent in sport. *Talent Dev. Excel.* 5, 21–34.

Davids, K., Araújo, D., and Shuttleworth, R. (2005). "Applications of dynamical systems theory to football," in *Science and Football V: The Proceedings of the Fifth World Congress on Science and Football*, eds T. Reilly, J. Cabri, and D. Araújo (London, UK: Routledge), 556–569.

Díaz-Cueto, M., Hernández-Álvarez, J. L., and Castejón, F. J. (2012). La estrategia preguntas-respuestas como clave de la enseñanza comprensiva del deporte en Educación Física estudio de casos. *Cultura y Educación* 24, 279–288.

García-González, L., Moreno, M. P., Moreno, A., Iglesias, D., and del Villar, F. (2009). Estudio de la relación entre conocimiento y toma de decisiones en jugadores de tenis, y su influencia en la pericia deportiva [Relation between knowledge and decision making in tennis players and its influence in sport expertise]. *Revista Internacional de Ciencias del Deporte.* 17, 60–75.

García-López, L. M., González-Víllora, S., Gutiérrez, D., and Serra, J. (2013). Development and validation of the game performance evaluation tool (GPET) in soccer. *Revista Euroamericana de Ciencias Del Deporte* 2, 89–99.

Gil-Arias, A., del Villar, F., García-González, L., Moreno, A., and Moreno, M. P. (2015). Effectiveness of video feedback and interactive questioning in improving tactical knowledge in volleyball. *Perceptual Motor Skills* 121, 635–653. doi: 10.2466/30.PMS.121c23x9

Harvey, S., Cushion, C. J., and Massa-Gonzalez, A. N. (2010). Learning a new method: teaching games for understanding in the coaches' eyes. *Phys. Educ. Sport Pedagogy* 15, 361–382. doi: 10.1080/17408980903535818

Travassos, B., Araújo, D., Davids, K., Vilar, L., Esteves, P., and Vanda, C. (2012). Informational constraints shape emergent functional behaviours during performance of interceptive actions in team sports. *Psychol. Sport Exerc.* 13, 216–223. doi: 10.1016/j.psychsport.2011.11.009

The Importance to the Superiority in Attack in Task Design. A Study from the Non-Linear Pedagogy

Alba Práxedes[1], Fernando Del Villar[2], Miguel Domínguez[1], David Pizarro[1], Alberto Moreno[1]

[1]Faculty of Sport Sciences, University of Extremadura, Cáceres, Spain
[2]Field Physical Education and Sport, Rey Juan Carlos University, Madrid, Spain
apraxedesp@gmail.com

Introduction: To optimize players' tactical abilities, coaches need to design training sessions with representative learning tasks (Pinder et al., 2011), such as the Small-Sided and Conditioned Games (SSCG) that have been proposed to be an effective methodological tool for optimizing the tactical behaviour of athletes (Davids et al., 2013). On the other hand, Ayvazo and Ward (2011) point out coaches should consider that players need an affordable challenge for learning when designing training tasks. Thus, the level of opposition must be a constraint to have been manipulated because it facilitates the process of response selection and technical execution (Práxedes et al., 2016). Specifically, these authors point out that a lower level of opposition involves a lower defensive pressure and more time for attacking players with the ball to make decisions. Thus, the objective of this study was to analyze the effect, on tactical behavior of footballers, of equal (5 vs. 5) and unequal (5 vs. 4) numbers of outfield players in SSCG before to present to footballers game situations with equal number of players per team.

Method: The participants were 20 footballers from the under-14 category of two teams from two different Spanish clubs. Both teams had the same level of sports expertise and participated in the same league. The decision-making and the execution of pass and dribbling actions, during small-sided games, were evaluated using the GPET (Game Performance Evaluation Tool; García-López et al., 2013). Moreover, it was assessed the duration of ball possession and the number of ball touches through a hand notation analysis systems. In each training session, teams performed two SSCG (5 vs. 4 + 5 vs. 5 or 5 vs. 5 + 5 vs. 5) during periods of 14 min. Each sequence was developed in two different days. The pitch size of the SSG was 40 m × 25 m (see Table 1).

TABLE 1: Schematic of the study design.

	SSCG 1 (7′) Initial situation	Recovery 2′	SSCG 2 (7′) Final situation
Day 1 + 3	5 vs. 4		5 vs. 5
Day 2 + 4	5 vs. 5		5 vs. 5

Results: With respect to the decision-making and execution variables, there are no significant differences between the two final equality situations in any of the variables studied. However, and with respect to the initial situations, there are significant differences being the means higher in the situation of superiority, except in the execution of the dribbling, in which there are no significant differences. On the other hand, regarding the number of touches and the duration of ball possession, it is observed that in the situation of equality that was preceded by another in superiority, means are higher than in the situation of equality that was preceded by another situation of equality. In addition, in the initial situations, means are higher in superiority than in equality.

Discussion and conclusion: After the results obtained, it is observed as regardless of the situation prior to the equality you propose to the player, the performance will be the same in this. However, in that initial situation, means are significantly higher in the situation of superiority, except in the execution of the driving, in which there are no differences. Therefore, it seems to improve the decision-making of the pass in situations of equality, it is indifferent that the initial situation you present to players, although means are higher in this initial situation of superiority. It does not occur with the dribbling, an action that seems to require equal situations, in which there is a more direct contact between an attacker and a defender, with the objective that in situations of equality, which will occur in the matches, players do it well (Práxedes et al., in press). Moreover, it should be noted that in situations of equality, the participation of the player and the ball possession are greater if we present to player easier initial situations (e.g. numerical superiority in attack), being this participation also greater in these initial situations. In addition, when there are superiority, participation and continuity are greater in the game, leading to a better development of technical-tactical skills (Ericsson et al., 2006). To conclude, we point out that before presenting to players situations in numerical equality, situations with superiority in attack are recommended, in which the player makes better decisions and consequently has more contact with the ball and greater continuity in the game. However, to improve driving, it may be necessary only equality situations.

Acknowledgements

This work was supported by the Ministry of Employment, Enterprise and Innovation of the Government of Extremadura (Spain) through the European Regional Development funds.

REFERENCES

Ayvazo, S., and Ward, P. (2011). Pedagogical content knowledge of experienced teachers in physical education: functional analysis of adaptations. *Res. Q. Exerc. Sport* 82, 675–684. doi: 10.1080/02701367.2011.10599804 PMID:22276409

Davids, K., Araújo, D., Correia, V., and Vilar, L. (2013). How small-sided and conditioned games enhance acquisition of movement and decision-making skills. *Exerc. Sport Sci. Rev.* 41, 154–161. doi: 10.1097/JES.0b013e318292f3ec PMID:23558693

Ericsson, K. A., Charness, N., Feltovich, P., and Hoffman, R. R. (2006). *Cambridge Handbook of Expertise and Expert Performance*. Cambridge: Cambridge University Press.

García-López, L. M., González-Víllora, S., Gutiérrez, D., and Serra, J. (2013). Development and validation of the game performance evaluation tool in soccer. *Revista Euroamericana de Ciencias Del Deporte* 2, 89–99.

Pinder, R. A., Davids, K., Renshaw, I., and Araújo, D. (2011). Representative learning design and functionality of research and practice in sport. *J. Sport Exerc. Psychol.* 33, 146–155. doi: 10.1123/jsep.33.1.146 PMID:21451175

Práxedes, A., Del Villar, F., Pizarro, D., and Moreno, A. (in press). The impact of nonlinear pedagogy on decision-making and execution on young football players according to the game actions. *J. Hum. Kinet*.

Práxedes, A., Moreno, A., Sevil, J., Pizarro, D., and Del Villar, F. (2016). Effect of equal and unequal numbers of players in small-sided football games on tactical performance in young players. *J. Sport Pedagogy Res.* 2, 22–29.

Hypernetworks: Capturing the Multilayers of Cooperative and Competitive Interactions in Soccer

João Ramos[1,2], Rui J. Lopes[1,3], Pedro Marques[4], Duarte Araújo[5]

[1]ISCTE-Instituto Universitário de Lisboa, Lisbon, Portugal
[2]Universidade Europeia, Laureate International Universities, Estrada da Correia, Lisboa, Portugal
[3]Instituto de Telecomunicações, Lisbon, Portugal
[4]Football Performance, City Football Services, Manchester, United Kingdom
[5]CIPER, Faculdade de Motricidade Humana, Universidade de Lisboa, Cruz Quebrada Dafundo, Portugal
joaoramos@meuemail.net

Introduction: Hypernetwork theory brings together the micro–meso–macro levels of analysis of interaction-based complex systems (Johnson, 2013; Boccaletti et al., 2014). This study considers team synergies (Araújo and Davids, 2016), where teams and athletes are co-evolving subsystems that self-organize into new structures and behaviors. The emergent couplings of players' movements have been studied, considering mostly the distance between a player and the immediate opponent (e.g., Headrick et al., 2012), and other interpersonal distance measures (Passos et al., 2011; Fonseca et al., 2013). Such emergent interpersonal behavior of soccer teams can be captured by multilevel hypernetworks approach that considers and represents simultaneously the minimal structure unit of a match (called simplex). More stable structures are called backcloth. The backcloth structure that represents soccer matches is not limited to the binary relations (*2*-ary) studied successfully by social networks analysis (SNA) but can consider also *n*-ary relations with $n > 2$. These simplices most of the times composed of players from both teams (e.g., 1 vs. 1, 2 vs. 1, 1 vs. 2, 2 vs. 2) and the goals. In a higher level of representation, it is also possible to represent the events associated, like the interactions between players and sets of players that could cause changes in the backcloth structure (aggregations and disaggregation of simplices). The main goal of this study was to capture the dynamics of the interactions between team players at different scales of analysis (micro—meso—macro), either from the same team (cooperative) or from opponent team players (competitive).

Methods: To analyze the interactions of players, we used proximity criteria (closest player) for defining the set of players in each simplex. The non-parametric feature of this method allows for the analysis of the sets (simplices) that emerge from spatiotemporal data of players and form simplices of different types. In this study, we first used the mathematical formalisms of hypernetworks to represent a multilevel team behavior dynamics, including micro (interactions between players established through interpersonal closest distance), meso (dynamics of a given critical event, e.g., goal scoring opportunity) and macro levels (dynamics of emerging local dominance).

We have applied hypernetworks analysis to soccer matches from the English premier league (season 2010–2011) by using two-dimensional player displacement coordinates obtained with a multiple-camera match analysis system provided by STATS (formerly Prozone).

Results: We studied different levels of analysis. At the micro level, we found:

i. The most common minimal simplices are 1 vs. 1 (25.0%), followed by 1 vs. 2 (10.31%), 2 vs. 1 (8.78%), and 2 vs. 2 (6.81%);

ii. Which players were more often connected forming the same simplices (see Table 1).

iii. Where did it take place (*heat maps*) in field game (Figure 1)?

In the meso level, we identified critical events dynamics such as:

i. Velocity of each player related to average velocity of the set;

ii. Changes of velocity and direction to break the symmetry of the set;

iii. Which players are central to break or maintain these symmetries.

The dynamics of simplices transformations near the goal depended on, significant changes in the players' speed and direction.

At macro level, we found how sets were related:

i. Emergent behavior analysis of players to promote local dominance analysis in critical events (see Figure 1);

Simplices are connected to one another, forming simplices of simplices including the goalkeeper and the goal.

Conclusion: The multilevel hypernetworks approach is a promising framework for soccer performance analysis once it captures cooperative and competitive interactions between players and sets of players. The spatiotemporal feature of the interactions between two or more players and sets of players are captured through the multilevel analyses and allows a richer understanding of real-world complex systems. Notably, players' moves can promote local dominance, i.e., moving to different directions from their closest players and increasing interpersonal distance; or moving to reduce interpersonal distances, either from their closest (typically) opponents or colleagues (local dominance). The identification of the most frequent simplices of players and their specific interactions, regarding local dominance, during a match is specific relevant information not only for analyzing the matches but also for preparation for future matches with different opponents.

TABLE 1: Relative frequency for the top 15 simplices in the analyzed match. (e.g., simplex $\sigma_{49} = a_5, b_{25};(1 \text{ vs. } 1)$ was found 30.2% of the time).

$\sigma_{49} = a_5, b_{25};(1 \text{ vs. } 1)$ 0.302	$\sigma_{178} = a_{10}, b_{18}, b_{21};(1 \text{ vs. } 2)$ 0.089
$\sigma_{25} = a_{10}, b_{18};(1 \text{ vs. } 1)$ 0.293	$\sigma_{177} = a_5, b_{17}, b_{25};(1 \; vs.2)$ 0.061
$\sigma_{54} = a_8, b_{26};(1 \text{ vs. } 1)$ 0.266	$\sigma_{240} = a_6, b_{24};(1 \; vs.1)$ 0.058
$\sigma_{48} = a_4, b_{19};(1 \text{ vs. } 1)$ 0.127	$\sigma_{408} = a_{11}, b_{17};(1 \; vs.1)$ 0.057
$\sigma_{24} = a_7, b_{21};(1 \text{ vs. } 1)$ 0.124	$\sigma_{171} = a_2, b_{20};(1 \; vs.1)$ 0.076
$\sigma_{182} = a_3, b_{22};(1 \text{ vs.} 1)$ 0.121	$\sigma_{331} = a_2, b_{16}, b_{20};(1 \; vs.2)$ 0.067
$\sigma_{63} = a_4, b_{16}, b_{19};(1 \text{ vs. } 2)$ 0.107	$\sigma_6 = a_7, a_{10}, b_{18}, b_{21};(2 \text{ vs. } 2)$ 0.064
$\sigma_{96} = a_3, a_{12}, b_{22};(2 \text{ vs. } 1)$ 0.096	

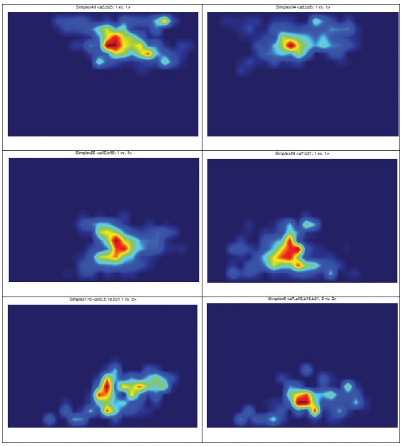


FIGURE 1: Heat map for simplices $\sigma_{49} = a_5, b_{25};(1 \text{ vs. } 1)$, $\sigma_{54} = a_8, b_{26};(1 \text{ vs. } 1)$ $\sigma_{25} = a_{10}, b_{18};(1 \text{ vs. } 1)$, $\sigma_{24} = a_7, b_{21};(1 \text{ vs. } 1)$, $\sigma_{178} = a_{10}, b_{18}, b_{21};(1 \text{ vs. } 2)$, and $\sigma_6 = a_7, a_{10}, b_{18}, b_{21};(2 \text{ vs. } 2)$.

REFERENCES

Araújo, D., and Davids, K. (2016). Team synergies in sport: theory and measures. *Front. Psychol.* 7:1449. doi: 10.3389/fpsyg.2016.01449 PMID:27708609

Boccaletti, S., Bianconi, G., Criado, R., Del Genio, C. I., Gómez-Gardenes, J., Romance, M., et al. (2014). The structure and dynamics of multilayer networks. *Phys. Rep.* 544, 1–122. doi: 10.1016/j.physrep.2014.07.001

Fonseca, S., Milho, J., Travassos, B., Araújo, D., and Lopes, A. (2013). Measuring spatial interaction behavior in team sports using superimposed Voronoi diagrams. *Int. J. Perform. Anal. Sport* 13, 179–189. doi: 10.1080/24748668.2013.11868640

Headrick, J., Davids, K., Renshaw, I., Araújo, D., Passos, P., and Fernandes, O. (2012). Proximity-to-goal as a constraint on patterns of behaviour in attacker–defender dyads in team games. *J. Sports Sci.* 30, 247–253. doi: 10.1080/02640414.2011.640706

Johnson, J. (2013). *Hypernetworks in the Science of Complex Systems*, Vol. 3. London: Imperial College Press.

Passos, P., Milho, J., Fonseca, S., Borges, J., Araújo, D., and Davids, K. (2011). Interpersonal distance regulates functional grouping tendencies of agents in team sports. *J. Mot. Behav.* 43, 155–163. doi: 10.1080/00222895.2011.552078 PMID:21400329

Effects of Temporal Numerical Imbalances on Individual Exploratory Behaviour during Football SSGs

A. Ric[1], A. Canton[1], C. Torrents[1], B. Gonçalves[2], J. L. Arjol[3], J. Sampaio[2], R. Hristovski[4]

[1]Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
[2]Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, CreativeLab Research Community, Vila Real, Portugal
[3]University of San Jorge, Zaragoza, Spain
[4]Faculty of Physical Education, Sport and Health, Saint Cyril and Methodius University, Skopje, Macedonia
angelric10@outlook.com

Introduction: Under the influence of match and training constraints, players are not able to arbitrarily explore large areas of available state space, resulting in associations between configurations (states) of movement or behaviours. This will lead to the formation of a hierarchical structure of behaviour with many temporary stable states (Hristovski et al., 2013). In this way, the exploratory behaviour is defined by the switching dynamics between those different temporary stable states. In football, this is a key concept because of the constantly changing environment force player to improvise and adapt to the teammates and opponent behaviours. And more specifically to the local numerical imbalances (Vilar et al., 2013). Therefore, the aim of this study was to identify if the exploratory behaviour of individual players when playing balanced 4 vs. 4 SSG is affected by inducing numerical imbalances on a timescale of several tens of seconds.

Methods: Fifteen professional football players participated in this study. They were informed about the research procedures, providing a prior informed consent. The local Institutional Research Ethics Committee approved the study, which also conformed to the recommendations of the Declaration of Helsinki. Three teams (A, B, and C) of five football players (four field players plus goalkeeper) played 6 small-sided games against each other (first, A vs. B; secondly A vs. C; and finally B vs. C) in two different SSG formats: balanced and imbalanced. Balanced SSG consisted in a gk+4 vs. 4+gk numerical relation during the whole 5 min game. Imbalanced SSG consisted in a numerical relation change by introducing one or two extra players on the game and leaving it on the timescale of tens of seconds. That is, first min.: gk+4 vs. 4+gk; second min.: gk+5 vs. 4+gk; third min. gk+4 vs. 5+gk; forth min.: gk+6 vs. 4+gk; and fifth min.: gk+4 vs. 6+gk. All SSG were played on a natural pitch measuring 40 m × 45 m. Each game involved 5-min. periods of play separated by 3-min. of passive rest. Data were gathered through a combination of systematic observation and the use of a 5 Hz non-differential global positioning system (SPI ProX, GPSports, Canberra, ACT, Australia). All SSG were recorded using a digital video camera. The video recording was processed and analysed using Lince software (Gabin et al., 2012), with an ad-hoc instrument being used to notate when and which players passed or received the ball. The tactical actions, interaction context, field zones and movement speed were determined using latitude and longitude coordinates exported from the GPS units and computed using dedicated routines in Matlab® (MathWorks, Inc., MA, USA) (for complete guidelines, see Folgado et al., 2014). These four specific variables allowed determining 37 different categories that defined the tactical configuration for each player. 1,500 configurations (1 for each 0.2 s) was used to form a binary matrix with 37 × 1,500 dimension. The average dynamic overlap, $<q_d(t)>$, was calculated as an average cosine auto-similarity of the overlaps between configurations with increasing time lag (for more details, see Hristovski et al., 2013). This measure allows detecting the exploratory behaviour on different timescales.

Results: The long-term exploratory breadth of the players was calculated as mean similarity of the plateau values of the dynamic overlap. The average values obtained for the two conditions were 0.23 ± 0.04 for balanced and 0.24 ± 0.05 for imbalance. *T*-test did not revealed significant differences between situation with and without extra players ($t = -1.44$, $df = 23$, $p = 0.16$) with a small effect size ($d = 0.20 \pm 0.26$).

Discussion and conclusion: The use of extra players is a common task constraint used during football training. However, there is a little research done in reference to it (Hill-Haas et al., 2010). Previous studies suggested the use of extra players to manipulate task constraints on a timescale of tens of seconds in order to enlarge the rate and breath of player's exploration (Ric et al., 2016). Under the current experimental setting, results did not show significant effect of extra players' imbalances on individual exploratory behavior. The results show how context dependent may be the effects of manipulation of numerical imbalance, and how carefully these differences have to be considered in order to reach general conclusions. These results also encourage considering the positioning of the extra players on the analysis. Furthermore, this type of constraint could have some effects on the exploratory behaviour for different age groups. More research is needed to know the effects of constraints manipulation on different time scales on the exploratory behaviour.

REFERENCES

Folgado, H., Duarte, R., Fernandes, O., and Sampaio, J. (2014). Competing with lower level opponents decreases intra-team movement synchronization and time-motion demands during pre-season soccer matches. *PLoS ONE* 9:e97145. doi: 10.1371/journal.pone.0097145 PMID:24817186

Gabin, B., Camerino, O., Anguera, M. T., and Castañer, M. (2012). Lince: multiplatform sport analysis software. *Proc. Soc. Behav. Sci.* 46, 4692–4694. doi: 10.1016/j.sbspro.2012.06.320

Hill-Haas, S. V., Coutts, A. J., Dawson, B. T., and Rowsell, G. J. (2010). Time-motion characteristics and physiological responses of small-sided games in elite youth players: the influence of player number and rule changes. *J. Strength Cond. Res.* 24, 2149–2156. doi: 10.1519/JSC.0b013e3181af5265 PMID:19834345

Hristovski, R., Davids, K., Araújo, D., Passos, P., Torrents, C., Aceski, A., et al. (2013). "Creativity in sport and dance: ecological dynamics on a hierarchically soft-assembled perception-action landscape," in *Complex Systems in Sport*, eds K. Davids, R. Hristovski, D. Araújo, N. Balagué, C. Button, and P. Passos (London: Routledge), 261–274.

Ric, A., Hristovski, R., Gonçalves, B., Torres, L., Sampaio, J., and Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *J. Sports Sci.* 34, 1723–1730. doi: 10.1080/02640414.2015.1136068 PMID:26758958

Vilar, L., Araújo, D., Davids, K., and Bar-Yam, Y. (2013). Science of winning soccer: emergent pattern-forming dynamics in association football. *J. Syst. Sci. Complex.* 26, 73–84. doi: 10.1007/s11424-013-2286-z

Network of Football Players Interactions According to the Match Period: A Case Study of the Bayern Munich vs. Real Madrid

Fabian Alberto Romero Clavijo[1], Umberto Cesar Corrêa[1], Marcos Rodrigo Trindade Pinheiro Menuchi[2]

[1]School of Physical Education and Sport, University of São Paulo, São Paulo, Brazil
[2]Santa Cruz State University, Ilheus, Bahia, Brazil
fromero@usp.br

Introduction: The football game can be defined as a dynamic process that emerges from the interactions between players whose cooperate and oppose forming two systems (teams) (Duarte et al., 2013). Those interactions occur simultaneously, change across the game and are influenced by the match status (Paixão et al., 2015). In order to investigate game dynamics, the social network analysis has been used to access play interaction patterns among teammates and has been used to identify the properties of the teams associated with collective performance. In this sense, studies have shown that high levels of co-relationships lead to increased team performance (Grund, 2012). For example, Clemente et al. (2015) conducted a study with football teams during FIFA World Cup 2014, and found that the number of goals scored was positively associated with the number of total links, network density and clustering coefficient. These characteristics suggest that the tendencies to teammates behave as a whole may be associated with better performances in team sports. Despite of that, there is still a gap on the understanding of how the networks interactions varies within the game while the score changes. Thus, this study aimed to analyze the network properties throughout the match period.

Method: The attacking plays were recorded and analyzed during the full match between Bayern Munich and Real Madrid on the UEFA Champions League 2016. To identify each position in the field, we classified the strategic positioning of players 1–11 each team. The network analysis comprised the construction of an adjacency matrix related to six time periods of 15 min across the match that represented the connections between nodes (player) with an adjacent node (teammate). The criteria to define the connection were the pass among players. For each pass between teammates, a value of 1 was coded, otherwise, a value of 0 was coded. All adjacency matrices were imported into Social Networks Visualizer version 2.2 (SocNetV) to be analyzed. Four network metrics were used for analysis: (i) density: overall relationship among teammates; (ii) centralization: homogeneity level of a network; (iii) clustering coefficient: degree of inter connectivity in the neighborhood of a given player; and (iv) centroid player: most recruited and connected node in the network.

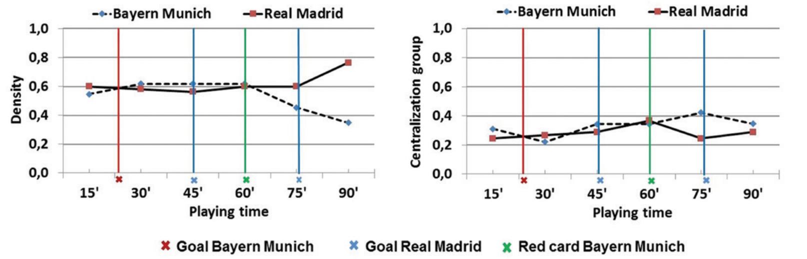


FIGURE 1: Descriptive values of density measures and centralization of each team in relation to match period. The vertical lines represent the moments in which goals were scored in the game.

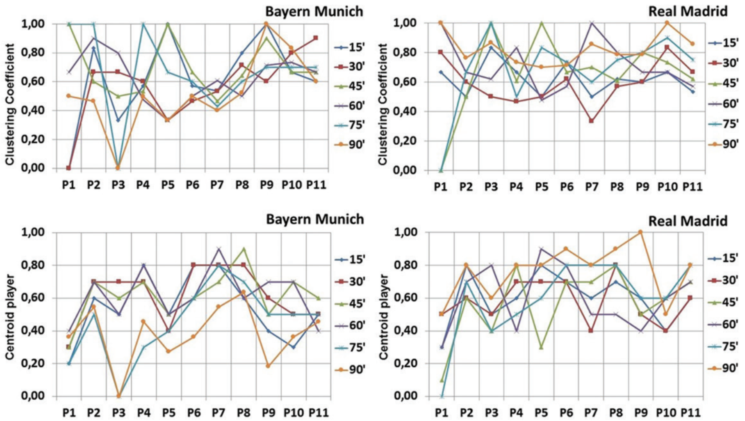


FIGURE 2: Descriptive values of centroid player and clustering coefficient of each player in relation to match period.

Results and discussion: The general properties of graphs can be seen in the Figure 1. It is possible to observe a difference of the density values between teams during the periods of the game. Real Madrid presented a higher density value in the last 30 min of the game. Density increase when the team was winning and needed to keep the score. On the other hand, the value of centralization was similar between the teams until the last 30 min, when Bayern Munich increased the centrality. This may have occurred because of the expulsion of a Bayern Munich player in the 61st minute and the need to score a goal. These results are consistent with the hypothesis that performance is related to co-relationships (Grund, 2012). The clustering coefficient and centroid players can be seen in the Figure 2. The clustering coefficient values show that Bayern Munich players 7, 8, 10, and 11 had similar intermediate and high values and players 1–5 had high variability along the game. Note that player 3 was sent off in the 61 min, therefore in the last two periods, his values were zero. In contrast, Real Madrid players showed intermediate-high values across the game, except the goalkeeper who had high and low values along the game. These results show that the midfielders and forwards of Bayern Munich, as well as all Real Madrid players tend to pass the ball to neighbor teammates. The centroid player values in Bayern Munich vary from player to player and along the match. The players with more regular values were 1, 2, 5, and 11. Note that the players 7 and 8 were the featured players in periods 4 and 3, respectively. Except the player 3 who was sent off in the 61 min, the lowest values in the fifth and sixth periods were found in players 1 and 9, respectively. On Real Madrid team, centroid player values were intermediate-high, except in player 1 who showed the lowest values in periods 3 and 5. The player 5 got higher values in period 4, and player 9 reached the highest value in the last period. These results show that there was not a featured player during the game, there was a tendency for players to present intermediate values throughout the game.

Conclusion: We conclude that team networks varied from match period. Specifically, that higher values in density, lower values in centralization group, and more regular values in clustering and centrality player measures lead to better team performance and winning the game.

REFERENCES

Clemente, F. M., Martins, F. M. L., Kalamaras, D., Wong, P. D., and Mendes, R. S. (2015). General network analysis of national soccer teams in FIFA World Cup 2014. *Int. J. Perform. Anal. Sport* 15, 80–96. doi: 10.1080/24748668.2015.11868778

Duarte, R., Araújo, D., Folgado, H., Esteves, P., Marques, P., and Davids, K. (2013). Capturing complex, non-linear team behaviours during competitive football performance. *J. Syst. Sci. Complex.* 26, 62–72. doi: 10.1007/s11424-013-2290-3

Grund, T. U. (2012). Network structure and team performance: the case of English Premier League soccer teams. *Soc. Network* 34, 682–690. doi: 10.1016/j.socnet.2012.08.004

Paixão, P., Sampaio, J., Almeida, H. C., and Duarte, R. (2015). How does match status affects the passing sequences of top-level European soccer teams? *Int. J. Perform. Anal. Sport* 15, 229–240. doi: 10.1080/24748668.2015.11868789

Unlocking African Football Potential: Acknowledging Athletes As Complex Systems— A Human Factors and Ergonomics Approach

Ben Ryan, Andrew Todd

Rhodes University, Grahamstown, South Africa
g08r5157@campus.ru.ac.za

The importance of conceptualizing the human as a component within a complex, dynamic system has become increasingly important in scientific research (Salmon et al., 2017). Within a sporting context this is effectively illuminated by Phillips et al. (2010), who recognized the comprehensive multidisciplinary theoretical rationale needed to understand all factors involved in performance. Furthermore, Till et al. (2016) notes that the nurturing of sporting talent is inherently multi-dimensional, and influenced by numerous physical, technical, and psychological factors. With emphasis on the influence of interacting constraints, it may therefore be preferable to adopt a multi-dimensional approach to sport-related phenomena, namely complex systems theory (Balagué et al., 2017). The globalization of soccer has resulted in squads being more heterogeneous in nature, which has important implications as talent identification and development is a complex interaction of both nature and nurture (Tucker and Collins, 2012). Individualized programs are therefore necessary to optimise the development pathway. Designing such programs requires a holistic understanding of the player, and unfortunately this complexity has seldom been tackled within traditional sports science methods, resulting in recent interest in systems related literature. Human factors and ergonomics (HFE) is an approach that has been used effectively to tackle complex systemic problems through a human centred systems approach. Interestingly, there has been a long standing acknowledgment of the role of HFE from a sports science perspective, particularly soccer (Reilly, 2005). Additionally, authors such as McLean et al. (2017) have advocated for the efficacy of this approach within a sports science framework. Unfortunately, such research has focused on athletes from developed regions, with little consideration of (a) the differential factors within the system for African and (b) the complex heterogeneous background of African athletes. The current research therefore adopts an HFE systems approach to understanding the unique set of interacting factors characteristic of African players. The use of systems ergonomics is well described by Wilson (2014), who identified six notions that are fundamental to successful systems theory application: systems, context, interactions, holism, emergence, and embedding. The application of these notions within the aforementioned context is therefore of the utmost importance.

Systems and holism: Unfortunately previous research has not adopted a systematic, holistic approach to understanding development of African soccer players. Sports science has often taken a reductionist approach; however, this over simplifies integration amongst organizational levels of living systems, and limits integration of biological and social sciences (Balagué et al., 2017). Results from such reductionist studies therefore often have limited practical value as there is little acknowledgement or integration of other influencing factors. The context is therefore a vital consideration.

Context: This is especially prevalent in Africa, with distinctly unique aspects that influence athlete development and performance. From poor infrastructure, poor education, the quadruple burden of disease, and historical injustice, the reality of the African player is vastly different to those previously studied. Thus, there are numerous complex interactions, within a highly unique context, that must be further acknowledged in order to represent the African athlete effectively.

Interactions and emergence: Understanding the interaction of factors unique to the African context remains limited as previous research has not placed focus on the sustainability of development programs. Additionally, the role of stakeholders has often been undervalued, failing to engage with emergent problems. To improve effectiveness of athletic development programs, there is a distinct need for the co-construction of knowledge, to identify barriers to system resilience.

Embedding: To achieve this, the researcher must embed themselves within the system. This is evident as simplistic reductionist approaches that have resulted in poor sustainability of development programs. The inability to acknowledge the vast number of factors affecting the reality of all stakeholders, often results in a poor relationship between science and practice. It is evident that a participatory approach to problem identification is needed, to facilitate improved system resilience. African soccer-related literature has therefore failed to truly engage with the uniqueness of the African athlete. Poor understanding has resulted in an inability to optimize both performance and talent development. This paper therefore has two primary outcomes: (1) Identify the key barriers to the African soccer player performance system in order to increase resilience. (2) And most importantly, take advantage of adaptive nature of athletes. African athletes have succeeded in spite of the vast number of factors affecting performance, showing themselves as highly adaptive systems. This paper therefore describes a new conceptual model for understanding and enhancing performance of African athletes, to reflect the complex, dynamic system at play. It further aims to utilize and optimize the adaptive and resilient nature of African athletes, providing an effective platform for African athlete development and performance.

REFERENCES

Balagué, N., Torrents, C., Hristovski, R., and Kelso, J. A. S. (2017). Sport science integration: an evolutionary synthesis. *Eur. J. Sport Sci.* 17, 51–62. doi: 10.1080/17461391.2016.1198422 PMID:27685425

McLean, S., Salmon, P. M., Gorman, A. D., Read, G. J., and Solomon, C. (2017). What's in a game? A systems approach to enhancing performance analysis in football. *PLoS ONE* 12:e0172565. doi: 10.1371/journal.pone.0172565

Phillips, E., Davids, K., Renshaw, I., and Portus, M. (2010). Expert performance in sport and the dynamics of talent development. *Sports Med.* 40, 271–283. doi: 10.2165/11319430-000000000-00000

Reilly, T. (2005). An ergonomics model of the soccer training process. *J. Sports Sci.* 23, 561–572. doi: 10.1080/02640410400021245 PMID:16195005

Salmon, P. M., Walker, G. H., Read, M., Goode, G. J., and Stanton, N. A. (2017). Fitting methods to paradigms: are ergonomics methods fit for systems thinking? *Ergonomics* 60, 194–205. doi: 10.1080/00140139.2015.1103385 PMID:26799501

Till, K., Jones, B. L., Cobley, S., Morley, D., O'Hara, J., Chapman, C., et al. (2016). Identifying talent in youth sport: a novel methodology using higher-dimensional analysis. *PLoS ONE* 11:e0155047. doi: 10.1371/journal.pone.0155047 PMID:27224653

Tucker, R., and Collins, M. (2012). What makes champions? A review of the relative contribution of genes and training to sporting success. *Br. J. Sports Med.* 46, 555–561. doi: 10.1136/bjsports-2011-090548 PMID:22535537

Wilson, J. R. (2014). Fundamentals of systems ergonomics/human factors. *Appl. Ergon.* 45, 5–13. doi: 10.1016/j.apergo.2013.03.021

Exploring the Differential Learning Routes on Creative and Tactical Behaviour in Association Football Players

Sara Santos[1], Diogo Coutinho[1], Bruno Gonçalves[1], Wolfgang Schöllhorn[2], Jaime Sampaio[1], Nuno Leite[1]

[1]Research Centre in Sports Sciences, Health Sciences and Human Development, CIDESD, CreativeLab Research Community, University of Trás-os-Montes and Alto Douro, Vila Real, Portugal

[2]Institute of Sport Science, Training and Movement Science, University of Mainz, Mainz, Germany

sarasantos_8@hotmail.com

Introduction: Creative behaviour is a higher-order disposition in football players and recent findings suggests that could be improved (Santos et al., 2017). Accordingly, an enrichment sport environment that provides freedom and challenge players to explore and adapt, will probably increase the emergence of the creative components, such as the attempts, fluency, and versatility. These components have been used to describe the creative behaviour in team sports: the attempts are recognized as an effort to perform different actions even unsuccessful movements; the fluency is related with the ability to perform as many effective movement actions as possible; and the versatility is identified as the ability to produce different actions (Santos et al., 2016). In this vein, the differential learning (DL) can be considered as a promising approach to enhance the creative behaviour (Henz and Schöllhorn, 2016). This approach is characterized by increasing the number of movement fluctuations, through no movement repetition and without corrections (Schöllhorn et al., 2012). The role of random variability in allowing players to acquire new and functional behaviours could be a way to unleash creativity. Moreover, it is possible that the variability induced by the DL approach may increase the players' ability to interact with the environment to unlock adaptive movement behaviours, and consequently lead to changes in tactical positioning. However, the available research is still scarce in exploring the DL effects on tactical aspects through small-sided games (SSG) situations. Hence, further evidence seems to be needed to understand how individual movement variability offered by DL approaches impacts the creative and tactical-related variables. Therefore, the aim of this study was to identify the effects of a DL training program on creativity and tactical behaviour in youth Association football players.

Methods: Twenty under 13 players were allocated into control (n = 10, age 11.4 ± 0.5 years) and an experimental group (n = 10, age 11.1 ± 0.5 years). Their performance was measured through a pre- to post-test design using SSG situations (Gk + 5vs5 + Gk). The SSG protocol was composed by two bouts of 6-min interspersed with 3 min of passive recovery. The experimental group participated in a 5-month DL program, three times a week for 30-min each session, embodied in SSG, while the control group participated in a typical small-sided games training program. In-game creativity was assessed through notational analyses of the creative components. Afterwards, the data were organized in a pre-prepared spreadsheet entitled Creativity Behaviour Assessment in Team Sports developed to measure the creativity in ball

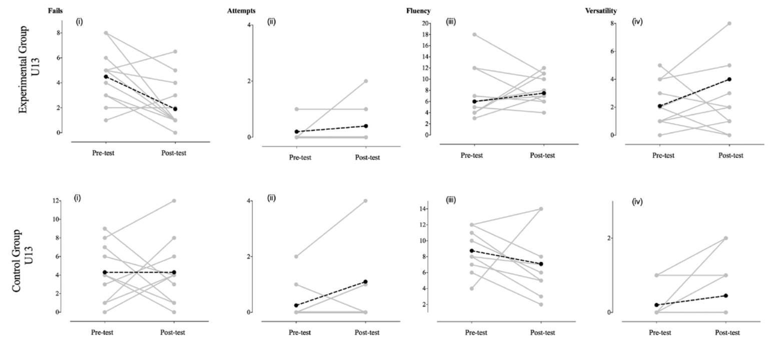


FIGURE 1: Results of the control and experimental groups in game creative behaviour. Note: grey solid lines indicated responses of individual participants and black dotted lines indicated mean value.

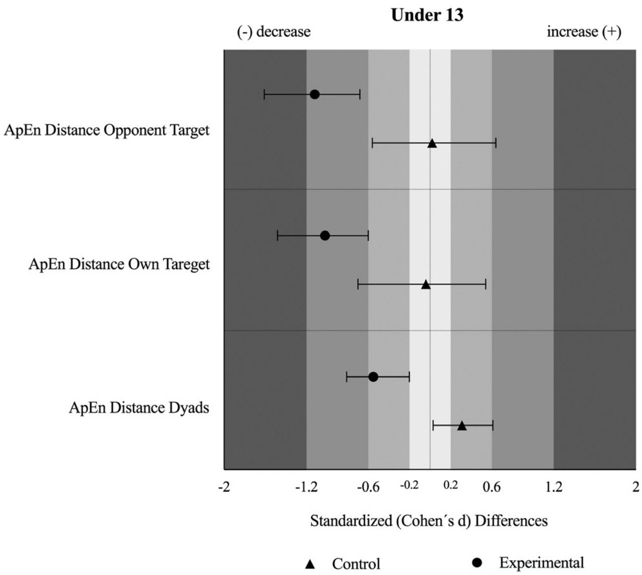


FIGURE 2: Standardised (Cohen's *d*) differences of approximate entropy (ApEn) values in pre- to post control and experimental groups.

possession during the game performance (Santos et al., 2017). Players' positional data during SSG was gathered by global positioning system units and used to process the regularity in the distance between teammates' dyads, the distance to the team own target, and the distance to the opponent team target. The regularity of these variables was then calculated using the approximate entropy (ApEn) technique.

Results: The results of the in-game creative components are presented in Figure 1 and the experimental group revealed a moderate decrease from the pre- to the post-test in fails measurements (difference in means; ±90 confidence limits: −1.8; ±1.2). Both control and experimental teams presented a moderate increase in their attempts (0.5; ±0.3, very likely and 0.3; ±0.3, likely). Regarding the fluency, there was a small decrease in the control team (−1.4; ±1.7) and an unclear trend in the experimental group. The mainly creative component stressed by the training program was the versatility which showed a moderate increase (0.3; ±0.4) in the experimental group. As observed in the Figure 2, the experimental team showed a small decrease in the ApEn values of the distance between dyads (9.8%; ±5.2%, very likely) and a moderate decrease in distance to the team and opponent targets (−17.1%; ±6.7%, most likely; −16.3%; ±6.2%, most likely, respectively).

Discussion and conclusion: Overall, the results support the assumption that a DL training program facilitates the development of the creativity components, namely the versatility of movement actions in youth football players, and promotes a substantial decrease of fails. Further, the values from the ApEn highlighted that players presented more regular positional behaviours after a DL training program (lower values in ApEn represents higher regularity in considered variables). These intentional positional adjustments may reveal a better understanding of the game, whereas the players showed higher regularity in their behaviours according to the game spatial references (targets) and interpersonal distance with teammates. Overall, it seems that the increase of the individual variability promoted by the DL approach may unlock the players' creative behaviour and favours the positioning regularity.

REFERENCES

Henz, D., and Schöllhorn, W. (2016). Differential training facilitates early consolidation in motor learning. *Front. Behav. Neurosci.* 10:199. doi: 10.3389/fnbeh.2016.00199 PMID:27818627

Santos, S., Jimenez, S., Sampaio, J., and Leite, N. (2017). Effects of the Skills4Genius sports-based training program in creative behavior. *PLoS ONE* 12:e0172520. doi: 10.1371/journal.pone.0172520

Santos, S., Memmert, D., Sampaio, J., and Leite, N. (2016). The spawns of creative behavior in team sports: a creativity developmental framework. *Front. Psychol.* 7:1282. doi: 10.3389/fpsyg.2016.01282 PMID:27617000

Schöllhorn, W., Hegen, P., and Davids, K. (2012). The nonlinear nature of learning – a differential learning approach. *Open Sport Sci. J.* 5, 100–112. doi: 10.2174/1875399X01205010100

Analysis of Volleyball Attack from the Markov Chain Model

David Sepulveda[1], Raúl Hileno[1], Antonio García-de-Alcaraz[2]

[1]National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
[2]LFE Research Group, Faculty of Physical Activity and Sport Sciences-INEF, Universidad Politécnica de Madrid, Madrid, Spain
d.sepulveda8@gmail.com

Introduction: Performance analysis provides objective information about players' and/or teams' behaviors (O'Donoghue, 2010) from a descriptive to a predictive way (McGarry, 2009). Preparation of a match is a kind of "predictive" scenario in which the coach organizes the team according to some performance indicators that interact with the opponent. In volleyball, most top teams use professional software, such as Data Volley, to analyze opponent's behaviors and to prepare a match (Silva et al., 2016). Performance indicators most commonly used in coaching focus on the player who attacks the ball, especially in the attack phase (complex I), and the influence of team's rotation. In a volleyball rally, the first set of actions performed by a team to build an attack is known as complex I (reception, set, and attack) and contribute most to final outcome (Laios and Kountouris, 2011). The set action has a great influence on attacker's performance (Bergeles et al., 2009) and is affected by team's rotation because of the number and role of players ready to attack (Durković et al., 2009). Volleyball research studies that focused on a predictive framework tend to use multivariate analysis (Afonso et al., 2012). Nevertheless, other net/wall sports employ another type of analysis such as Markov chain (McGarry and Franks, 1996; Pfeiffer et al., 2010). This technique is a discrete stochastic process that shows the probability of an event occurring based on previous state. Volleyball coaches and players may be interested in identifying opponent's tendencies behaviors in order to predict future ones. Thus, the aim of this study was to analyze the attack tendency in complex I in terms of a team's rotation using the Markov chain model.

Methods: A total of 373 completed complexes I were analyzed. These game sequences were performed by the starting setter of the Brazilian male team in all matches played in the 2012 Olympic Games (8 matches and 29 sets). The variables were (a) *number of rotation* in terms of setter's position (R1, R6, R5, R4, R3, and R2) and (b) *player who attacks* (S: setter; RA1: receiver–attacker closer to setter; RA2: receiver–attacker far from setter; MP1: middle player closer to setter; MP2: middle player far from setter; and OP: opposite player). The intra- and inter-reliability showed values over $\kappa = 0.91$. The transition probabilities between two states were calculated with two-dimensional contingency tables with Microsoft Office Excel 2016 (Microsoft Corp.,

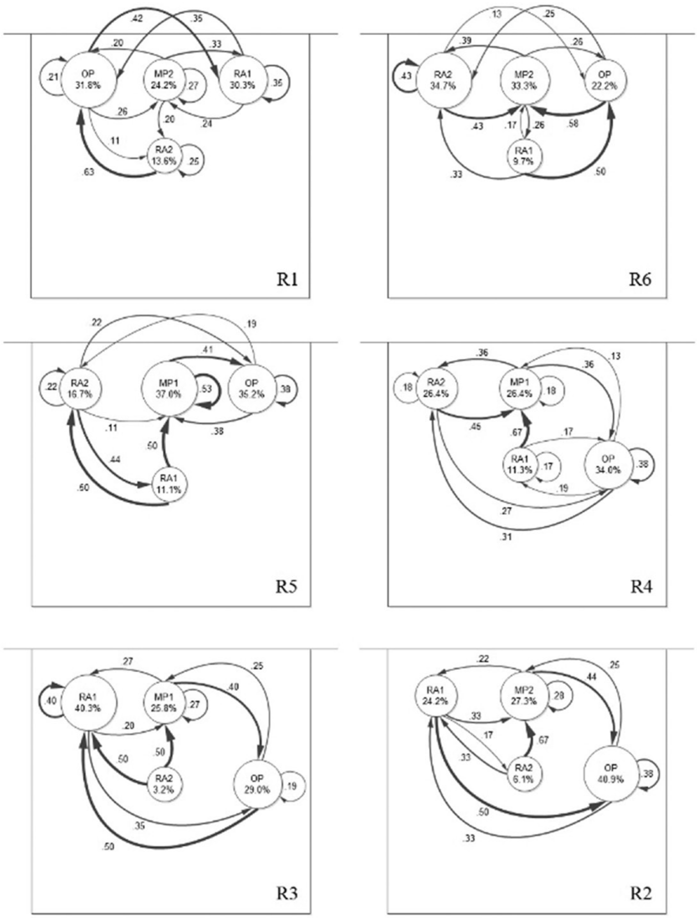


FIGURE 1: Analysis of attack options from the Markov chain model.

Redmond, WA, USA). The transition diagram was generated with Edraw Max v. 6 (EdrawSoft, Hong Kong, China). In this diagram, the nodes represented the state (player who attacked in his court area) and the size of the node showed the attack probability. The arrows represented the transition probabilities from one state to another (probability from 0 to 1) and arrow's size showed the transition probability among players (only the transition probabilities greater than 0.10 were shown).

Results: In terms of game rotation, the sequences observed in complex I were 17.7% (R1), 19.3% (R6), 14.5% (R5), 14.2% (R4), 16.6% (R3), and 17.7% (R2). Figure 1 shows the percentage of attack for each player in terms of team rotation. The probability of each attack option is shown in the following Markov chain. Setter's attack probability was omitted because of its low occurrence. As shown in R1, the player who participated mostly in attack was the opposite (31.8%). After the attack of this player, the probability of an attack from the receiver–attacker 1 was 0.42, followed by the middle player 2 with 0.26.

Discussion and conclusion: The Markov chain model may be a useful tool to analyze players' probability of attack (state probability) in terms of team rotation from the previous player who attacks (transition probability). This analysis allows coaches to analyze opponents' playing styles and make decisions before, during, and after the match. However, this analysis should include other contextual variables, such as game period, quality of opponent, etc., as they influence performance (Marcelino et al., 2012). Also, performance in previous actions (such as reception) should be taken into account because of their influence on setter's behaviors.

REFERENCES

Afonso, J., Esteves, F., Araújo, R., Thomas, L., and Mesquita, I. (2012). Tactical determinants of setting zone in elite men's volleyball. *J. Sports Sci. Med.* 11, 64–70. PMID: PMC3737848

Bergeles, N., Barzouka, K., and Nikolaidou, M. E. (2009). Performance of male and female setters and attackers on Olympic-level volleyball teams. *Int. J. Perform. Anal. Sport* 9, 141–148.

Durković, T., Marelić, N., and Rešetar, T. (2009). Rotation analysis of teams' performances at 2003 Youth European Volleyball Championship. *Kinesiology* 41, 60–66.

Laios, A., and Kountouris, P. (2011). Receiving and serving team efficiency in volleyball in relation to team rotation. *Int. J. Perform. Anal. Sport* 11, 553–561. doi: 10.1080/24748668.2011.11868573

Marcelino, R., Sampaio, J., and Mesquita, I. (2012). Attack and serve performances according to the match period and quality of opposition in elite volleyball matches. *J. Strength. Cond. Res.* 26, 3385–3391. doi: 10.1519/JSC.0b013e3182474269 PMID:22207260

McGarry, T. (2009). Applied and theoretical perspectives of performance analysis in sport: scientific issues and challenges. *Int. J. Perform. Anal. Sport* 9, 128–140. doi: 10.1080/24748668.2009.11868469

McGarry, T., and Franks, I. M. (1996). Development, application, and limitation of a stochastic Markov model in explaining championship squash performance. *Res. Q. Exerc. Sport* 67, 406–415. doi: 10.1080/02701367.1996.10607972 PMID:9016482

O'Donoghue, P. (2010). *Research Methods for Sports Performance Analysis*. Abingdon: Routledge.

Pfeiffer, M., Zhang, H., and Hohmann, A. (2010). A Markov chain model of elite table tennis competition. *Int. J. Sports Sci. Coach.* 5, 205–222. doi: 10.1260/1747-9541.5.2.205

Silva, M., Marcelino, R., Lacerda, D., and João, P. V. (2016). Match analysis in volleyball: a systematic review. *Monten. J. Sports Sci. Med.* 5, 35–46.

Tactical Constraints for Technical-Tactical Alphabetization in Youth Football

Jaime Serra-Olivares

Faculty of Education, University of Castilla-La Mancha, Ciudad Real, Spain
Jaime.serra@uclm.es

Introduction: Football teaching under the game-based approach is widely accepted. However, youth players still show tactical knowledge and game performance shortcomings (Serra-Olivares et al., 2015a,b,c,d, 2016). Therefore, there is a need of a higher theoretical understanding of the principles comprising the football teaching processes (e.g., the ecological psychology, dynamical systems and constraint-led approaches, and the game understanding representative task design methodologies). In this regard, the purpose of this research was to assess the influence of the modification of tactical constraints on game performance behaviours of youth football players.

Methods: A comparative study was designed to assess the decision-making skills of 160 youth Chilean football players (M SD) in 8 vs. 8 and 7 vs. 7 small-sided games. The first game was modified by the pedagogical principle of representation of the game-based approaches (8 vs. 8). The second game was modified by the representation and exaggeration pedagogical principles by pointing the importance of attacking width using the wings (7 vs. 7 with two goals for each team and without goalkeepers). Games are represented in the Figure 1. The Game Performance Evaluation Tool (GPET) was used for the analysis.

Results: The results were compared according to the type of small-sided game played. Parametric tests were performed in all cases: *ANOVA one factor* and the subsequent analysis of the effect size. Findings show significant differences in the players' game performance depending on the tactical constraints of the game (Table 1). A higher significant performance in the tactical context of advancing was observed in the 7 vs. 7 games ($F = 3.328$, $p < 0.05$, $r = 0.69$). Players' performance in the attacking tactical context was also better in the 7 vs. 7 games ($F = 2.383$, $p < 0.05$, $r = 0.52$).

Discussion and conclusion: Representative task design based on the adaptation and exaggeration of tactical constraints is revealed as an opportunity for proposing ecological games, which are contextualized to the player needs and the competition (Serra-Olivares et al., 2017). For these reasons, the technical-tactical alphabetization based on the tactical constraints is suggested as a chance for the development of high-quality football teaching processes.

FIGURE 1: Small-sided games modified by the pedagogical principles of the game-based approaches.

TABLE 1: Game performance of the players depending on the game played.

	8 vs. 8 small-sided game		7 vs. 7 playing width	
	M	SD	M	SD
Tactical adaptation to keeping the ball situations	82.00	12.78	85.44	14.00
Tactical adaptation to advancing situations	80.20	23.45	92.34	11.21
Tactical adaptation to attacking situations	64.80	26.32	87.22	17.72

REFERENCES

Serra-Olivares, J., García López, L. M., and Calderón, A. (2016). Game-based approaches, pedagogical principles and tactical constraints: examining games modification. *J. Teach. Phys. Educ.* 35, 208–218. doi: 10.1123/jtpe.2015-0125

Serra-Olivares, J., García-López, L. M., and Calderón, A. (2015a). Conocimiento específico de dominio táctico en futbolistas de 8-12 años. *Apunts Educ. Fís. Deportes*. 122, 36–43. doi: 10.5672/apunts.2014-0983.es.(2015/4).122.04

Serra-Olivares, J., García-López, L. M., Calderón, A., and Cuevas, R. (2015b). Relación del conocimiento táctico de jóvenes futbolistas con la edad, la experiencia y el nivel de pericia. *Cuad. Psicol. Deporte* 15, 105–112. doi: 10.4321/S1578-84232015000300010

Serra-Olivares, J., González Víllora, S., García-López, L. M., and Araújo, D. (2015c). Game-based approaches' pedagogical principles: exploring task constraints in youth soccer. *J. Hum. Kinet.* 46, 241–261. doi: 10.1515/hukin-2015-0053 PMID:26240668

Serra-Olivares, J., González-Víllora, S., and García-López, L. M. (2015d). Effects of the modification of task constraints in 3 vs. 3 small-sided soccer games. *S. Afr. J. Res. Sport Phys. Educ. Recreation* 37, 119–129.

Serra-Olivares, J., García-López, L. M., and Gutiérrez-Díaz del Campo, D. (2017). Conocimiento táctico de niños de 7 a 13 años en función del contexto deportivo. *Rev. Psicol. Deporte* 26, 135–144.

Measuring Player Density in Australian Rules Football Using Gaussian Mixture Models

Bartholomew Spencer[1], Stuart Morgan[2], John Zeleznikow[1], Sam Robertson[1]

[1]*Institute of Sport, Exercise and Active Living (ISEAL), Victoria University, Melbourne, VIC, Australia*
[2]*Department of Rehabilitation, Nutrition and Sport, School of Allied Health, La Trobe University, Melbourne, VIC, Australia*
bartholomew.spencer@live.vu.edu.au

Introduction: Many existing metrics describing the spatial occupancy of groups have limited applications should be dynamic, relative representation of space be required. Playing space, or surface area, describes the spatial coverage of teams and has featured in complex systems literature (e.g., Frencken et al., 2011). Dominant regions quantify the dominance of individuals *via* computing the areas in which they are closest and have been used to classify passes (Horton et al., 2014) and quantify court space (Cervone et al., 2016). These metrics describe spatial dominance in binary terms (i.e., as belonging completely, not partially, to an object), hence are insufficient to describe the relative amount of space at specific locations. We propose the use of Gaussian mixture models (GMMs) for measuring the density of groups. GMM is a probabilistic model that fits k Gaussians to a dataset and has widespread applications such as tennis shot prediction (Wei et al., 2016). We use characteristics of this methodology to analyze congestion in Australian Rules football (AF), a sport played between teams of 18 players. We demonstrate how GMM can be used to calculate density at spatial locations in the analysis of kicking targets and possessions. Its case-specific ability to be used interchangeably with existing metrics is demonstrated *via* temporal analysis of density. Different types of congestion are identified through the clustering of GMM characteristics.

Methods: Data were collected from training matches by the Western Bulldogs Football Club (WB), a team in the Australian Football League (AFL). Training matches were 15 vs 15 players. Players wore Catapult tracking devices (Catapult Innovations, Australia) with data recorded at 10 Hz. Ball possession was manually annotated. GMMs were fit using a consistent number of Gaussians ($k = 3$). Model fit is evaluated using the Bayesian information criterion (BIC), where smaller values indicate better fits (Schwarz, 1978). Hence, BIC can act as a proxy for the congestion at a given time. Spatial density is calculated using the probability density function (PDF), where μ_m and Σ_m are mean and covariance of Gaussian m:

$$\mathrm{PDF} = \sum_{m=1}^{k} \frac{1}{(2\pi)\left|\Sigma_m\right|^{1/2}} \exp\left[-\frac{1}{2}\left(x-\mu_m\right)^T \Sigma_m^{-1}\left(x-\mu_m\right)\right]. \tag{1}$$

Gaussians are evaluated *via* weight, $w_m \left(\sum_{m=1}^{k} w_m = 1\right)$, and determinant, $|\Sigma_m|$. Visual representations of GMMs are shown in Figure 1. BIC and playing space (area within the convex hull) were calculated and grouped by quarter. To test the concurrent validity of BIC, the level of association between the metrics was calculated using the Spearman correlation coefficient (ρ). Differences in BIC between quarters were compared using one-way ANOVAs. Level of association between PDF and distance from goalpost of kicking targets was computed using ρ. Kicking targets were investigated by ranking

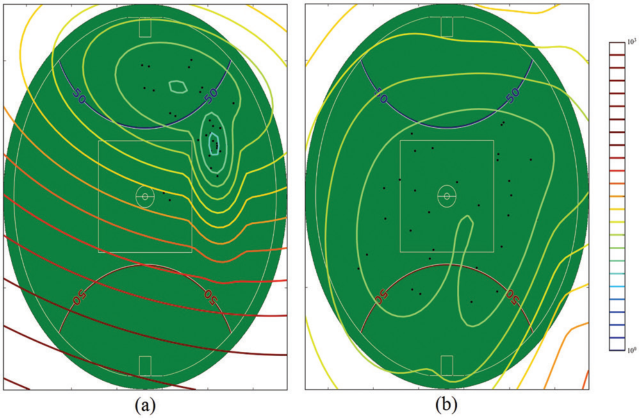


FIGURE 1: Scatterplots of high **(A)** and low **(B)** congestion with density visualized *via* negative log-likelihood contours. Examples were fit with three Gaussians and BIC values are **(A)** 449.14 and **(B)** 589.46.

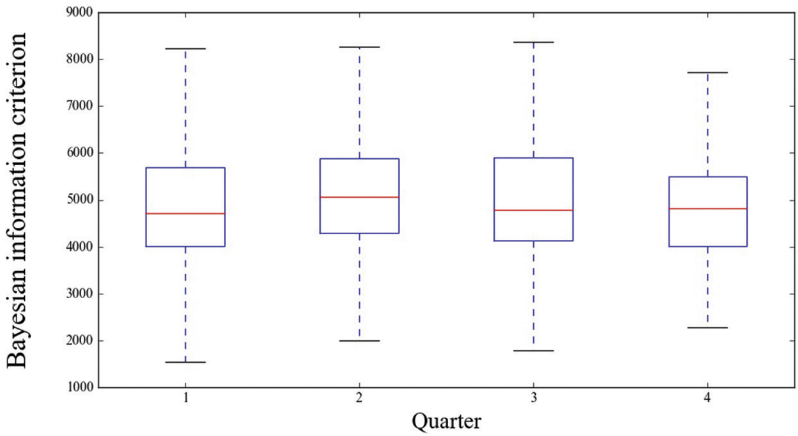


FIGURE 2: BIC readings for an individual match.

the density of targets relative to their teammates. The change in density and sample entropy (Richman and Moorman, 2000) of possession chains were analyzed. Gaussian characteristics were recorded and clustered into eight groups *via* k-means.

Results: Quarter comparisons, Figure 2, revealed a difference in BIC ($p < 0.001$). Quarters 3 and 4 were found to have no significant difference ($p = 0.28$) and had means between those of quarters 1 and 2. BIC was highly correlated with playing space ($p = 0.57$, $p < 0.05$). There was a weak negative correlation between kicking target density and distance from objective ($p = -0.11$, $p > 0.05$). Frequency analysis revealed a minor skew towards targets of lower density (mean rank 6.31 out of 14). Descriptive statistics (mean ± SD) for change in density of successful and unsuccessful possession chains were 0.51 ± 0.81 and 0.09 ± 1.00, respectively. Mean sample entropy of successful and unsuccessful possession chains were 0.056 ± 0.053 and 0.089 ± 0.067. Results reveal less regularity and greater change in density during successful possessions. k-Means clustering revealed a group with high variance containing Gaussians of above average weight and determinants. Remaining Gaussians were arbitrarily grouped and a continuous scale of congestion is noted, rather than distinct groups.

Discussion and conclusion: GMM can be used to calculate the overall (BIC) or point-specific (PDF) density of spatiotemporal data in sports. The ability to calculate continuous density may allow for simpler spatial analysis than existing metrics. While our methods were demonstrated on AF, GMM would likely be effective on similar spatiotemporal datasets. Applied analysis revealed no clear trend in congestion and weak correlation between distance from objective and kicking targets. Further analysis revealed a tendency to kick to players with low density and analysis of possessions revealed that successful chains have lower entropy and greater changes in density. GMM methodology may have practical applications in match preparation, should the importance of space be validated. Future applications include analyzing rule changes and developing predictive models, where density is a desirable feature.

REFERENCES

Cervone, D., Bornn, L., and Goldsberry, K. (2016). "NBA court realty," in *MIT Sloan Sports Analytics Conference 2016*, Boston.

Frencken, W., Lemmink, K., Delleman, N., and Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *Eur. J. Sport Sci.* 11, 215–223. doi: 10.1080/17461391.2010.499967

Horton, M., Gudmundsson, J., Chawla, S., and Estephan, J. (2014). Classification of passes in football matches using spatiotemporal data. *arXiv preprint arXiv:1407.5093*.

Richman, J. S., and Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *Am. J. Physiol. Heart Circ. Physiol.* 278, H2039–H2049. PMID:10843903

Schwarz, G. (1978). Estimating the dimension of a model. *Ann. Stat.* 6, 461–464. doi: 10.1214/aos/1176344136

Wei, X., Lucey, P., Morgan, S., Reid, M., and Sridharan, S. (2016). ""The thin edge of the wedge": accurately predicting shot outcomes in tennis using style and context priors," in *MIT Sloan Sports Analytics Conference 2016*, Boston.

Free Play with Equipment to Foster Exploratory Behavior in Preschoolers

Carlota Torrents[1], Assumpta Ensenyat[1], Ángel Ric[1], Mercè Mateu[2], Robert Hristovski[3]

[1]*Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain*
[2]*Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Barcelona, Barcelona, Spain*
[3]*Complex Systems in Sport Research Group, Sts. Cyril and Methodius University, Skopie, Macedonia*
ctorrents@inefc.es
aensenat@inefc.es
angelric10@outlook.com
mmateusea@gmail.com
robert_hristovski@yahoo.com

Introduction: Ecological approaches that analyse children's behaviour suggest that we should describe environments not in terms of forms but in terms of affordances (Heft, 1988), or of what possibilities of action they offer to the performer (Gibson, 1979). This concept has evolved to define affordances as invitations, as they do not cause behaviour, but instead they facilitate that certain actions are more likely to occur (Prieske et al., 2014). Following this principle and considering children's behaviour as an emergent property of the complex relationship between the performer and the environment (Araújo et al., 2006; Chow et al., 2007; Kelso, 2009), it can be hypothesized that the modification of the play equipment available to the children will produce some behaviours that will be more likely to occur than others and that some equipment will afford more exploratory behaviour than others. Exploratory behaviour is defined as the variety and quantity of responses performed by the children, considering the characteristics of the actions and all of their possible combinations. In previous research, this measure has been used to study the variety of the responses of dancers (Torrents et al., 2015) or soccer players (Ric et al., 2016) when modifying task constraints. The aim of this study was to evaluate if diverse types of play equipment differentially constraint the exploratory behaviour in preschoolers when playing freely.

Methods: 14 children, 3–4 years old played with four different types of equipment: without equipment (NE), with balls and hoops (BH), with kerchiefs and papers (KP), and with mats and wedges (MW). They were asked to play freely in the school's sports hall (20 m × 20 m) in four trials of 6 min interspersed with recess pauses of approximately 10 min between each. All trials were video-recorded and a systematic observation instrument was used to notate actions and interactions with partners and equipment, which were subsequently analyzed by means of an analysis of the dynamic overlap order parameter (<q_{stat}>, measured to identify the rate and breadth of exploratory behaviour on different time scales). Repeated measures ANOVA and Wilcoxon matched paired test were used to compare the effect of the four trials on exploratory behaviour. The significance alpha level was set at $p \leq 0.05$ for all analyses. Effect size was estimated as the mean standardized difference between the mean of each group divided by the pooled standard deviation. Values of 0.2–0.5 represent small differences, 0.5–0.8 moderate differences, and >0.8 large differences according to Cohen *d*'s (Cohen, 1992).

Results: Results showed significant differences between the <q_{stat}> of the KP situation compared with playing with the other equipment, being clearly higher playing with KP (large effect). Playing without equipment also produced a significant higher <q_{stat}> value compared with playing with BH and MW (large effect). When comparing the *alpha value* (slope of the initial relaxation part of the overlap), results showed that playing with KP produced a lower slope than playing with the other equipment (large effect), and playing without equipment produced a lower slope than playing in all the other situations (large effect).

Discussion and conclusion: These results suggest that sport equipment, including gymnastic equipment and portable sport equipment (balls and hoops) seems to enhance the exploration of different movement configurations, compared to portable non-sport equipment (kerchiefs and papers) or playing without equipment.

REFERENCES

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

Chow, J. Y., Davids, K., Button, C., Shuttleworth, R., Renshaw, I., and Araujo, D. (2007). The role of nonlinear pedagogy in physical education. *Rev. Educ. Res.* 77, 251–278. doi: 10.3102/003465430305615

Cohen, J. (1992). A power primer. *Psychol. Bull.* 112, 155–159. doi: 10.1037/0033-2909.112.1.155

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Heft, H. (1988). Affordances of children's environments: a functional approach to environmental description. *Child. Environ. Q* 5, 29.

Kelso, J. A. S. (2009). "Coordination dynamics," in *Encyclopedia of Complexity and System Science*, ed. R. A. Meyers (Berlin: Springer-Verlag), 1537–1564.

Prieske, B., Withagen, R., Smith, J., and Zaal, F. T. J. M. (2014). Affordances in a simple playscape: are children attracted to challenging affordances? *J. Environ. Psychol.* 41, 101–111. doi: 10.1016/j.jenvp.2014.11.011

Ric, A., Hristovski, R., Gonçalves, B., Torres, L., Sampaio, J., and Torrents, C. (2016). Timescales for exploratory tactical behaviour in football small-sided games. *J. Sports Sci.* 414, 1–8. doi: 10.1080/02640414.2015.1136068 PMID:26758958

Torrents, C., Ric, Á., and Hristovski, R. (2015). Creativity and emergence of specific dance movements using instructional constraints. *Psychol. Aesthet. Creat. Arts* 9, 65–74. doi: 10.1037/a0038706

Ecological Theories, Non-Linear Practise and Creative Collaboration at AIK Football Club

James Vaughan[1†], Maurici A. López-Felip[2‡], Mark O. Sullivan[3†], Dennis Hörtin[†]

[1]*School of Human Movement and Nutrition Sciences, University of Queensland, Brisbane, QLD, Australia*
[2]*Centre for the Ecological Study of Perception and Action, University of Connecticut, Mansfield, CT, United States*
[3]*Centre for Sports Engineering Research, Sheffield Hallam University, Sheffield, United Kingdom*
james.vaughan@aik.se
maurici.lopez_felip@uconn.edu
mark.osullivan@aik.se
dennis.hortin@aik.se
[†]*Research & Development Department, AIK FF Stockholm.*
[‡]*Team Sports Department at Futbol Club Barcelona, Barça Innovation Hub.*

Introduction: Living systems have been defined as self-organizing developmental systems due to the coactive, coequally and coevolving parts (Gottlieb, 2000). In this spirit, in the developmental practices at AIK Football Club (Stockholm, Sweden) our teams are considered as complex systems developing over time. Thus, requiring our players through a practice programme design to be tuned to the lawful information specifying the affordance-effectivity mutuality (Turvey, 2015) not only at the task level but also at the levels of society and culture. To achieve that, AIK's research group embarked on a program of action research to bridge the theory-practise gap and better understand the ecological dynamics at the core of player development. The approach adopted by our group is found on the recognition that many youth sport systems fail to account for the complexity and non-linearity of human development. Human sub-systems develop at different levels and often act as rate limiters on performance. Therefore, we recognise that talent is not defined by a young athlete's fixed set of genetic or acquired components. Talent should be understood as a dynamically varying relationship between the constraints imposed by the tasks experienced, the physical and social environment, the motivational climate and the personal resources of a performer (Araújo et al., 2006; Duarte et al., 2012; Hristovski et al., 2012). To bridge the theory-practise gap, the Athlete Talent Development Environment (ATDE: Heneriksen et al., 2010; Larsen et al., 2013) is utilised to inform and organise transdisciplinary research approaches and ground AIK's coach development within a broader ecological context (see Figure 1). Further research pursuits began with a collaborative program of research with the Team Sports Department at FC Barcelona. The focus of this collaboration is the study of collective behaviour across the life span of developmental systems that are composed of more than one single organism (e.g., in soccer, players must coordinate

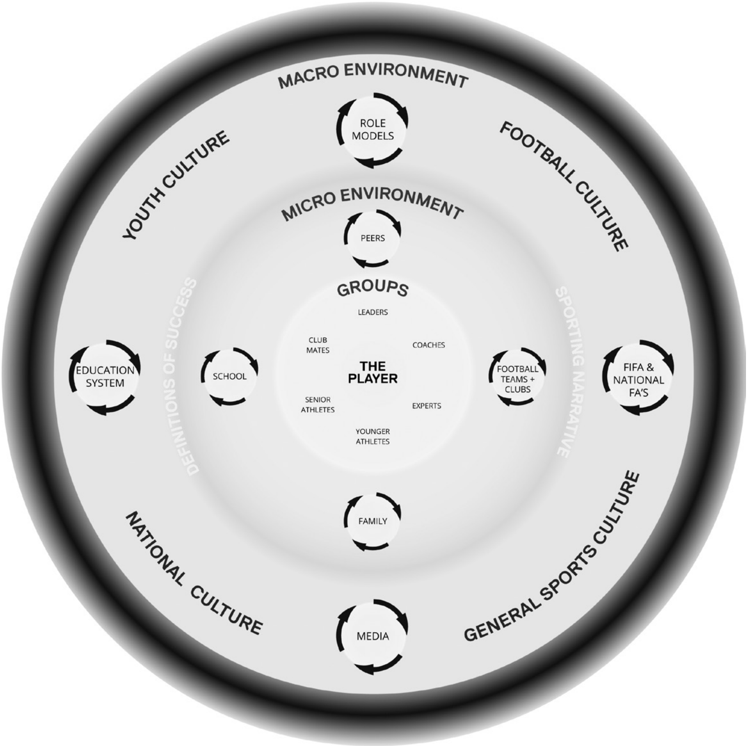


FIGURE 1: Illustrates a theoretical framework for understanding the broader ecological context. Adapted from "Athlete Talent Development Environment," by Heneriksen et al. (2010). Copyright 2016 the Player Development Project.

their actions with others across many different spatial and temporal scales to be successful). And while recent research has focused on elucidating the mechanisms that facilitate large-scale interactions, the identification of the fundamental, self-organizing principles that underlie team dynamics remains an unresolved matter. In addition, researchers have conducted studies of developmental systems in sports science in which the study of individual skills and interpersonal coordination are limited to comparisons between performance of experts and their novices' counterparts (i.e., performance from a first to a second test), rather than changes of behavior over time.

Methods: Our first attempt to address these two issues is a study with two elite U-14 football teams. The goal was to identify potential differences of team coordination dynamics between these groups and with previous matches from professional adult

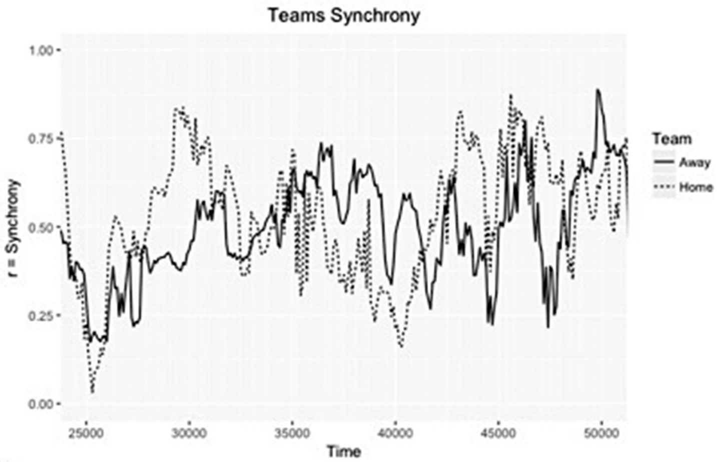


FIGURE 2: Illustrates a time window of teams' activity during the match. Team synchrony was derived by first getting a measure of the relative angle of each player to the goal of interest (i.e., the goal attacked by the team in possession of the ball).

players in which positional data were collected (see Figure 2). Player position data were obtained *via* Polar Team Pro (at a sampling rate of 1.0 Hz) for an entire U-14 football match at the Lennart Johansson Academy Trophy (i.e., two halves of 25 min). These GPS monitors could reliably capture positional raw data (2D) based on the latitude and longitude positions of all players throughout the match. Then, footballer's angle relative to the direction of the active goal (i.e., the goal being currently attacked) was submitted to Cluster Phase Analysis (CPA), creating a time-series of Kuramoto parameter values describing each team's synchrony at every time step.

Results: Preliminary results show that all the mean values of cluster amplitude for the angle ranged between 0.84 and 0.99 in both groups. These values are similar to those found in football (Duarte et al., 2013) or in intentional oscillatory rhythmic movements of rocking chairs (Frank and Richardson, 2010).

Discussion and conclusion: Implications of measuring team dynamics for understanding collective developmental systems in sports will be discussed with further analysis on our preliminary data sets.

REFERENCES

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

Duarte, R., Araújo, D., Correia, V., and Davids, K. (2012). Sport teams as superorganisms: implications of sociobiological models of behaviour for research and practice in team sports performance analysis. *Sports Med.* 42, 633–642. doi: 10.1007/BF03262285

Duarte, R., Araújo, D., Correia, V., Davids, K., Marques, P., and Richardson, M. J. (2013). Competing together: assessing the dynamics of team-team and player-team synchrony in professional association football. *Hum. Mov. Sci.* 32, 555–566. doi: 10.1016/j.humov.2013.01.011 PMID:24054894

Frank, T. D., and Richardson, M. J. (2010). On a test statistic for the Kuramoto order parameter of synchronization: an illustration for group synchronization during rocking chairs. *Physica D* 239, 2084–2092. doi: 10.1016/j.physd.2010.07.015

Gottlieb, G. (2000). Environmental and behavioral influences on gene activity. *Curr. Dir. Psychol. Sci.* 9, 93–97. doi: 10.1111/1467-8721.00068

Heneriksen, K., Stambulova, N., and Roessler, K. K. (2010). A holistic approach to athletic talent development environments: a successful sailing milieu. *Psychol. Sport Exerc.* 11, 212–222. doi: 10.1016/j.psychsport.2009.10.005

Hristovski, R., Davids, K., Passos, P., and Araújo, D. (2012). Sport performance as a domain of creative problem solving for self-organizing performer-environment systems. *Open Sports Sci. J.* 5, 26–35. doi: 10.2174/1875399X01205010026

Larsen, C. H., Alfermann, D., Henriksen, K., and Christensen, M. K. (2013). Successful talent development in soccer: the characteristics of the environment. *Sport Exerc. Perform. Psychol.* 2, 190–206. doi: 10.1037/a0031958

Turvey, M. T. (2015). Quantum-like issues at nature's ecological scale (the scale of organisms and their environments). *Mind Matter* 13, 7–44.

Time-Variability Properties of Acceleration during a Running Test

P. Vázquez[1], **Ll. Montull**[1], **X. Reche**[2], **N. Balagué**[1], **R. Hristovski**[3]

[1]*Complex Systems in Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Barcelona (UB), Barcelona, Spain*
[2]*Futbol Club Barcelona, Barcelona, Spain*
[3]*Complex Systems in Sport Research Group, Faculty of Physical Education, Sport and Health, University of Ss. Cyril and Methodius, Skopje, Macedonia*
pablovazjus@gmail.com

Introduction: Changes in the time-variability properties of a kinematic variable during a quasi-isometric exercise performed until exhaustion has been recently revealed (Vázquez et al., 2016). These changes, presumably informing about the state of the temporal couplings between the neuromuscular system's components, provided information about the dynamic mechanisms that lead to exhaustion. In this study, we aimed to detect the changes in the variability of acceleration during a 12 min exhausting running exercise.

Methods: Eight healthy experienced runners (seven males and one female; 39.37 ± 6.19 years old) volunteered to participate in the study. They were asked to run as much distance as possible during 12 min (Cooper test). Their running acceleration was recorded through WIMU accelerometer devices (Realtrack Systems S.L, Almería, Spain) placed on the L3 (Schütte et al., 2016). The sample recording frequency was established at 100 Hz. Participants run in two different groups to avoid possible recording interferences during the test. An 11-point Likert-type scale with anchors ranging from 0 (*not at all*) to 10 (*greatly*) was administered upon test completion to register the level of runner's commitment to the test. The Rate of Perceive Exertion (CR-10) was recorded at the end of the run. Multifractal Detrended Fluctuation Analysis (MFDFA) was conducted on the first and last minute of the recorded acceleration time series, each part containing $N = 4{,}096$ data points. The comparison of the MFDFA spectrum of the acceleration data was conducted by a t-test between the initial and the last minute of the test.

Results: All runners reported a relatively high level of commitment to the test (8.25 ± 1.03), and reported an RPE = 8.37 ± 0.74 at the end. They run a total distance of 2,847.50 ± 214.79 m over 12 min and their mean HR was 173.62 ± 8.23 beat/min. The MFDFA analysis of the acceleration time series recorded during the initial and final running minutes showed a reduction of the MFDFA spectrum in five athletes (see the example in Figure 1), and an increment in the MFDFA spectrum in three athletes. The first group reported higher RPE values (≥9) at the end of the test and had higher

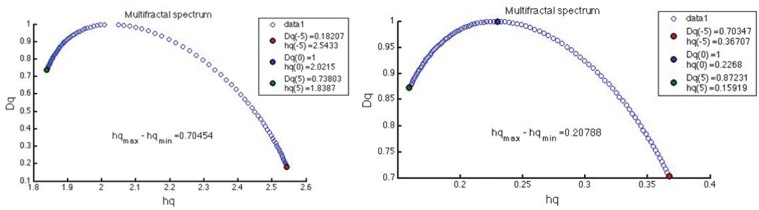


FIGURE 1: Example of initial (left) and final (right) multifractal spectrum width (MFDFA) in one participant who approached exhaustion. On the x axis is represented the q-order Hurst exponent (hq) from negative to positive q. On the y axis is represented the singularity dimension (Dq) of the time series.

HR values (≥180), while the second group reported lower RPE values (≤8) and had lower HR values (≤160).

Discussion and conclusion: The results differentiate two groups of runners, those who approached exhaustion and those who did not approach it. The reduction in the MFDFA spectrum of the acceleration during the test was found only in the first group. This reduction suggests a change in the psychobiological mechanisms used to negotiate the test demands as the running time increased, fatigue accumulated, and exhaustion was approaching. These results are similar to those found by Vázquez et al. (2016) during a quasi-isometric exercise. On the other hand, the runners who did not approach exhaustion, showed an increment in the MFDFA spectrum of running acceleration. This increment in the temporal variability suggests that they could adapt the neuromuscular system to the test demands. In conclusion, despite more evidences are needed, the study of the temporal variability of acceleration during running seems a promising way to determine the system's adaptability to effort.

REFERENCES

Schütte, K. H., Aeles, J., De Beéck, T. O., van der Zwaard, B. C., Venter, R., and Vanwanseele, B. (2016). Surface effects on dynamic stability and loading during outdoor running using wireless trunk accelerometry. *Gait Posture* 48, 220–225. doi: 10.1016/j.gaitpost.2016.05.017 PMID:27318455

Vázquez, P., Hristovski, R., and Balagué, N. (2016). The path to exhaustion: time-variability properties of coordinative variables during continuous exercise. *Front. Physiol.* 7:1–8. doi: 10.3389/fphys.2016.00037 PMID:26913006

Performance Profiles of Basketball Players in NBA According to Anthropometric Attributes and Playing Experience

Shaoliang Zhang[1,2,3], Alberto Lorenzo[1], Miguel-Angel Gómez[1], Nuno Mateus[3], Bruno Gonçalves[3], Jaime Sampaio[3]

[1]*Faculty of Physical Activity and Sports Sciences, Polytechnic University of Madrid, Madrid, Spain*
[2]*School of Physical Education and Sports Science, South China Normal University, Guangzhou, China*
[3]*Research Center in Sports Sciences, Health Sciences and Human Development, CIDESD, CreativeLab Research Community, Vila Real, Portugal*
zsl.inef@gmail.com

Introduction: Recruiting players in team sports is a very complex process. For example, in basketball, the anthropometric attributes and playing experience seem to appear as key factors to be accounted for selection and allocation to game-specific positions. Naturally, the tallest and heaviest players play closer to the basket, while smallest players are usually placed in perimeter positions. Additionally, experience may be another important factor to be considered in the players' selecting process. Previous research has summarized that expert players have a significant advantage over novices in reading game, decision-making, and anticipating events (Williams and Ford, 2008). Considering these statements, describing technical and physical performance profiles using different anthropometric characteristics and playing experiences might reveal new fine-tuned information to improve research models and support coaching staffs' decisions. Thus, the aim of this study was to classify and describe player performances from different groups of anthropometric and playing experience characteristics.

Methods: A total of 699 games were selected based on balance score inclusion criteria in the 2015–2016 NBA regular season. The players who played less than 500 min in the whole season were excluded from the sample, which limited the sample to a total of 354 players with 12,724 performance records. In addition, 17 game actions and events were selected as variables in the analyses. A two-step cluster with log-likelihood as the distance measure and Schwartz's Bayesian criterion was carried out to classify basketball players according to their anthropometric characteristics and playing experience. Afterwards, a descriptive discriminant analysis was conducted to identify which variables best discriminate the obtained clusters.

Results: There were five groups automatically obtained, whose details were presented in Figure 1 [mean (95% confidence interval)]. Follow-up discriminant analysis revealed three statistically significant functions, the first two yielded 88.8% of the cumulative variance (canonical correlations of 0.80 and 0.51, respectively). The reclassification of the cases in the original groups was moderate (59%). The first function had stronger emphasis on offensive rebounds (SC = 0.65) and defensive rebounds (SC = 0.64), whereas the second function was mainly emphasized by performance obtained in passing-related variables like touches (SC = –0.82), passes made (SC = –0.81), and assists (SC = –0.57). Additionally, in shooting aspects, three-point field goals made (SC = –0.41) and missed (SC = –0.41) were emphasized in the function 1, while two-point field goals made (SC = –0.34) and missed (SC = –0.34) were highlighted in the function 2. Furthermore, blocked shots (SC = 0.58), personal fouls (SC = 0.32), and turnovers (SC = –0.45) were also respectively emphasized in the function 1 and function 2. The assists were the only variable commonly highlighted in both functions. Players from TopHW-LowE group presented a relatively higher association with discriminant variables from function 1 (offensive and defensive rebounds, blocks, personal fouls) and performed well in two-point field goals made and missed from function 2, in comparison with other clustered groups. Although MiddleHW-MiddleE players presented the lowest association with discriminant variables in the function 1, the number of turnovers was lower compared with other groups. The MiddleHW-TopE group showed a very similar profile than players from as almost same trend as those from TopHW-LowE. The LowHW-LowE players had worst performance (two-point field goals made and missed, passes made, and touches) in function 2. The LowHW-MiddleE players had a higher association with discriminate variables in function 1 and function 2 (three-point field goals made and missed and passing-related variables), but had the worst performance in explained variables (offensive and defensive rebounds, personal fouls, and blocked shots) from function 1.

Discussion and conclusion: Outcomes from TopHW-LowE group showed that tallest and heaviest players were highly specialized in rebounding, inside shooting, screening, or drawing fouls (Sampaio et al., 2006). Additionally, the number of turnovers was lower for MiddleHW-MiddleE players. It is possible that middle experienced

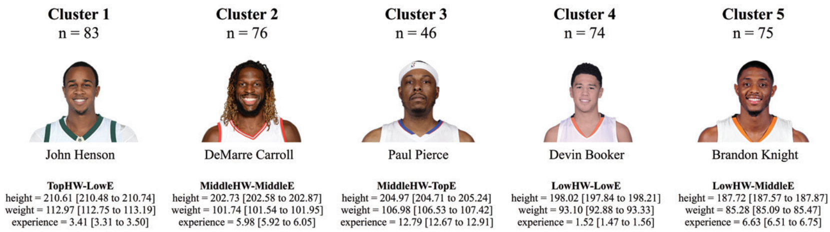


FIGURE 1: Describe statistics of the five cluster groups. Note: The presented players are the most representative for each cluster (less distance to cluster centroid). Abbreviation: TopHW-LowE: Top height and weight with low experience; MiddleHW-MiddleE: Middle height and weight with middle experience; MiddleHW-TopE: Middle height and weight with top experience; LowHW-LowE: Low height and weight with low experience; LowHW-MiddleE: Low height and weight with middle experience.

players can maintain peak performance in the technical and physical aspect in the NBA league. These players can effectively reduce turnovers to help teammates perform offensive tasks. Players from MiddleHW-TopE group showed the same trend as those from TopHW-LowE group. In fact, previous studies indicated that players' experience can help making more informed decisions, for example, by accurately judging the falling points of the ball and achieving an advantageous position to secure rebounds (Kioumourtzoglou et al., 1998). Players from LowHW-LowE had the worst performance in passing-related variables, while LowHW-MiddleE group showed the opposite trend. In summary, different performance profiles were identified by machine learning approaches using anthropometric characteristics and playing experiences, and there were some similarities and dissimilarities in discriminate variables between different performance profiles. These findings can be used to improve players' selection process and preparation.

REFERENCES

Kioumourtzoglou, E., Derri, V., Tzetzls, G., and Theodorakis, Y. (1998). Cognitive, perceptual, and motor abilities in skilled basketball performance. *Percept. Mot. Skills* 86, 771–786. doi: 10.2466/pms.1998.86.3.771 PMID:9656269

Sampaio, J., Janeira, M., Ibáñez, S. J., and Lorenzo, A. (2006). Discriminant analysis of game-related statistics between basketball guards, forwards and centres in three professional leagues. *Eur. J. Sport Sci.* 6, 173–178. doi: 10.1080/17461390600676200

Williams, A. M., and Ford, P. R. (2008). Expertise and expert performance in sport. *Int. Rev. Sport Exerc. Psychol.* 1, 4–18. doi: 10.1080/17509840701836867

Physical Performance in Match of Teams in the Chinese Football Association Super League: Effects of Match Location, Period, and Ball Possession Status

Changjing Zhou, Alberto Lorenzo Calvo, Yixiong Cui, Shaoliang Zhang

Faculty of Physical Activity and Sport Sciences, Technical University of Madrid, Madrid, Spain
zhoujiayi52123@126.com

Introduction: Performance analysis in football has provided insightful information on the technical–tactical and physical performance of European league teams, but there is scarce investigation in Asian football, Chinese Football Association Super League (CSL) could serve as an ideal model as it has recently attracted a lot of elite players and coaches, bringing the latest concepts of training and match tactics. Football is a highly complex sport incorporating interplay between physical and technical–tactical factors of players (Bradley et al., 2013). Ball possession was found to be strongly associated with match outcome and other technical indicators (Lago, 2009), but less is known about its interaction with physical performance. Additionally, previous studies tried to analyze the influence of ball possession on the movement performance. However, they failed to standardize the data based on the ball possession. Therefore, the aim of this study was to compare physical performance based on in/out-of-possession considering different situational scenarios in CSL.

Methods: Teams' tracking data of 240 matches were collected from the 2016 CSL, using Amisco (Amisco, Nice, France) tracking system. Three situational variables were included: home and away teams; first and second half of the match; and in and out of possession. For physical performance, the following indicators were determined: total distance run (m), distance covered (m) in high-speed running (19.1–23 km/h), and sprinting (>23 km/h); total numbers of high-speed running and sprinting. In order to avoid the misinterpretation of physical performance, all distance-related data were standardized by ball possession percentage using the following formulas:

$$DIs = DI/PIP * 50\% \quad (1)$$

$$DOs = DO/POP * 50\% \quad (2)$$

where DI = distance covered in possession; PIP = percentage in possession; DO = distance covered out of possession; and POP = percentage out of possession. Afterwards, magnitude-based inferences and precision of estimation was employed to compare physical performance between home and away teams within the following match scenarios: (i) first and second half and (ii) with and without ball possession, *via* standardized mean differences and respective 90% confidence intervals. Magnitudes of clear differences were assessed as follows: <0.20, trivial; 0.20–0.60, small; 0.61–1.20, moderate; 1.21–2.0, large; and >2.0, very large. Likelihood of the magnitude to be clear was defined as follows: <0.5% most unlikely; 0.5–5, very unlikely; 5–25%, unlikely; 25–75%, possibly; 75–95%, likely; 95–99.5%, very likely; and >99.5%, most likely (Batterham and Hopkins, 2006).

Results: The percentage of ball possession of the home team was possibly higher than away teams (ES = 0.24), but it only happened in the first half (ES = 0.39, very likely) (see Figure 1). Home teams spent possibly more time in the opposing half (ES = 0.26) and had possibly more numbers of sprints (ES = 0.21) at the first half. Furthermore, home teams ran possibly longer distance with high-speed running (ES = 0.22) when in possession and covered likely more distance in sprinting at the second half (ES = 0.30). When home and away teams were out of possession, they ran most likely more distance in total running (ES = 0.65, ES = 0.73, respectively) and high-speed running (ES = 0.75, ES = 0.91, respectively). Moreover, home teams ran likely more in sprinting with possession than without possession (ES = 0.33). Concerning the first and second half, home teams and away teams had likely more total running distance in possession (ES = 0.34, ES = 0.32, respectively) and out of possession (ES = 0.29, ES = 0.30, respectively) in the first half than the second half.

Discussion: Home teams in CSL have more ball possession than away teams, which was in agreement with prior studies (Lago and Martín, 2007), but in this research it

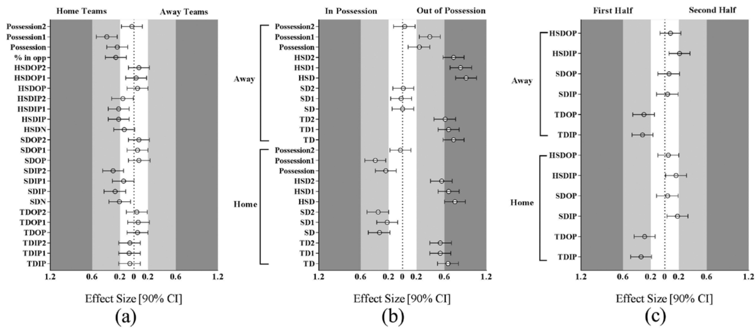


FIGURE 1: Effect sizes of differences in physical performance variables of **(A)** home teams vs. away teams; **(B)** home/away teams in possession vs. out of possession; and **(C)** home/away teams in the first half vs. in the second half. Legends: TD, total distance; SD, sprint distance; HSD, high-speed distance; possession, percentage of ball possession; IP, in possession; OP, out of possession; 1, first half; 2, second half.

only happened in the first half, and this was highlighted by a decrease in total distance in and out of possession at the second half. Home advantage could affect the physical distribution strategy in that when the home teams were in possession, they ran longer distance in high-speed running at the first half and in sprinting at the second half. It was likely that at the first half, home players have sufficient concentration and strength to keep overall attacking and synchronization through high-speed running. While at the second half, when their physical condition descended, their forwards or full-backs might choose to pressure the opponents through more sprinting towards the goal of opponent. All teams had similar performance in high-speed running and total distance when they were out of possession, which was probably due to the fact that teams without ball possession might be expected to cover more distance at a higher speed to pressure the offenders to regain possession (Bradley et al., 2011).

REFERENCES

Batterham, A. M., and Hopkins, W. G. (2006). Making meaningful inferences about magnitudes. *Int. J. Sports Physiol. Perform.* 1, 50–57. doi: 10.1123/ijspp.1.1.50 PMID:19114737

Bradley, P. S., Carling, C., Archer, D., Roberts, J., Dodds, A., Di Mascio, M., et al. (2011). The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches. *J. Sports Sci.* 29, 821–830. doi: 10.1080/02640414.2011.561868 PMID:21512949

Bradley, P. S., Lago-Peñas, C., Rey, E., and Gomez Diaz, A. (2013). The effect of high and low percentage ball possession on physical and technical profiles in English FA Premier League soccer matches. *J. Sports Sci.* 31, 1261–1270. doi: 10.1080/02640414.2013.786185 PMID:23697463

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *J. Sports Sci.* 27, 1463–1469. doi: 10.1080/02640410903131681 PMID:19757296

Lago, C., and Martín, R. (2007). Determinants of possession of the ball in soccer. *J. Sports Sci.* 25, 969–974. doi: 10.1080/02640410600944626 PMID:17497397

ABSTRACTS POSTER SESSIONS

Does Prospective Control of Preparatory Heart Rate Responses Occur during Biathlon Events?

Silje Dahl Benum, Ruud van der Weel, Øyvind Sandbakk, Audrey van der Meer

Norwegian University of Science and Technology (NTNU), Trondheim, Norway
sdbenum@gmail.com

Introduction: Biathlon is an Olympic winter sport that combines two essentially different sport skills, namely cross-country skiing in the skating technique and rifle shooting. A biathlon competition involves cross-country skiing, where the biathletes ski several 2–5 km laps in rolling terrain, interspersed with five shots of rifle shooting, alternating between the prone and standing position (International Biathlon Union, 2016). For each miss at the shooting range either 150 m of added skiing or a 1-min penalty is added to the final competition time. Successful biathlon performance thus depends on high aerobic power and well-developed skiing efficiency, as well as precise and rapid shooting abilities (Luchsinger et al., 2015). Biathletes usually ski at an intensity of 85–95% of maximum heart rate (HRmax) during competitions. However, a high heart rate accompanied by a high breathing frequency can be detrimental to shooting performance, since precise shooting requires the rifle to be held steady when aiming (Gallicchio et al., 2016). It might thus be beneficial for biathletes to regulate down their heart rate when approaching the shooting range. In addition, biathletes face diverse types of terrain, challenging them to regulate the metabolic intensity according to the demands of the terrain. Therefore, biathletes may prospectively increase their heart rate prior to, for example, a challenging uphill. The same type of heart rate regulation is expected to occur in connection with the start of a biathlon competition. Regulation of heart rate prior to the above events requires the biathlete to perceive what is going to happen in the near future so as to prepare the body accordingly, an ability that has been termed prospective control (Montagne, 2005; Lee, 2009). The aim of this study was to investigate preparatory heart rate patterns during simulated biathlon events to find evidence of prospective control. Prospective control was investigated in an ecologically valid field test, where electrocardiography (ECG) was continuously measured. The possible occurrence of prospective heart rate control was investigated in three central situations: (a) at the start, (b) when approaching uphill terrain during skiing, and (c) before shooting. We expected that biathletes would show prospective control in the form of an increase in heart rate prior to the start and the uphill terrain, and that a decrease in heart rate would occur prior to shooting.

Methods: The 10 national-level, junior (17.4 ± 1.3 years) male biathletes who participated skied 6–8 laps in a standardized biathlon course, where each lap was followed by 5 shots in the standing position. ECG data from the participants were collected continuously using a portable measuring system for human physiological data, the Equivital LifeMonitor (Hidalgo, UK). The data were used to calculate the instantaneous heart rate (IHR) which represents the participants' heart rate per second. The changes in heart rate during the 30 s period before the start, uphill, and shooting were analysed. At the start, the experimenter visually presented the remaining time before the start in seconds and gave verbal forewarnings at 30, 15, and 10 s before start. Perceptual information about the uphill and shooting range was readily available to the participants. In addition, the beginning of the uphill was indicated by a visible line drawn in the snow. GPS-position was tracked using a GPS watch at 1 Hz (Garmin Ltd.).

Results: Figure 1 shows the change in IHR for each of the participants during the last 30 s prior to start. IHR increased in the 30 s preceding the start, and this increase was especially pronounced during the last 15 s preceding the start ($p < 0.001$), with heart rate increasing by more than 10 beats per minute (BPM). IHR also increased during the 30 s prior to the start of the uphill ($p < 0.001$), but only when the biathletes approached the hill to actually ski up it, not when they continued to ski a flat control round instead. Finally, IHR decreased by 3.5 BPM during the final 30 s leading up to the shooting ($p < 0.001$), despite the fact that skiing speed was maintained at the same level (i.e., above 20 km/h).

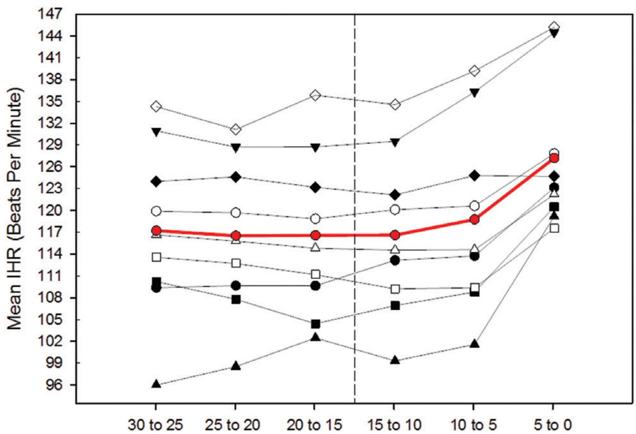


FIGURE 1: Increase in mean instantaneous heart rate (IHR) and the overall average (in red) for nine participants during the 30 s prior to the start of a simulated biathlon competition.

Discussion and conclusion: This study indicates that biathletes are able to prospectively control their heart rate prior to the start, when approaching an uphill section, and before shooting, allowing them to optimally prepare the body for the upcoming event. This was most clearly shown through the increase in heart rate observed in anticipation of the start, occurring while the participants were standing stationary at the starting line. This was further corroborated by the increase in heart rate found when biathletes were approaching the uphill section, which clearly differed from the situation when they continued to ski on a flat control round. Furthermore, the biathletes decreased their heart rate when they were approaching the shooting range, despite the fact that skiing speed was maintained. In conclusion, the use of prospective control of heart rate in this context may represent an optimal mechanism for anticipating the forthcoming physical effort, thereby optimally preparing the body for the challenges that lie ahead.

REFERENCES

Gallicchio, G., Finkenzeller, T., Sattlecker, G., Lindinger, S., and Hoedlmoser, K. (2016). Shooting under cardiovascular load: electroencephalographic activity in preparation for biathlon shooting. *Int. J. Psychophysiol.* 109, 92–99. doi: 10.1016/j.ijpsycho.2016.09.004 PMID:27619492

International Biathlon Union. (2016). *Annexes to the IBU Event and Competition Rules Adopted by the 2016 Congress*. Available at: http://www.biathlonworld.com/downloads/

Lee, D. N. (2009). General tau theory: evolution to date. *Perception* 38, 837–850. doi: 10.1068/pmklee

Luchsinger, H., Sandbakk, Ø, Schubert, M., Ettema, G., and Baumeister, J. (2015). A comparison of frontal theta activity during shooting among biathletes and cross-country skiers before and after vigorous exercise. *PLoS ONE* 11:e0150461. doi: 10.1371/journal.pone.0150461

Montagne, G. (2005). Prospective control in sport. *Int. J. Sport Psychol.* 36, 127–150.

Constraints-Led Approach: Calibration in a Volleyball Action

P. Caldeira, A. Paulo, J. Infante, D. Araújo

CIPER, Faculty of Human Kinetics, University of Lisbon, Lisbon, Portugal
paulocaldei@gmail.com

Introduction: Constraints-led Approach (CLA) pedagogical principles are informed by a learner-environment centred non-linear pedagogy (Chow et al., 2016) providing learning/training opportunities that encourage self-organization under constraints, infuse constrained variability by means of representative task design, promotes information-movement couplings, supports adaptive development, and gives performers the initiative to explore functional solutions without specific verbal instructions (Davids et al., 2003). When applying CLA, constraints can be manipulated to enhance skill acquisition in sport, namely, by task design that guides the performer through the phases of (i) search: exploring degrees of freedom to achieve a task goal; (ii) discover: exploring task solutions and stabilizing them; and (iii) exploit: exploiting perceptual-motor degrees of freedom (Renshaw et al., 2015). Focusing on the Exploitation phase that relates to calibration was the performer exploits system degeneracy to situational demands and effective goal achievement (Davids et al., 2012). The aim of this study was to compare the effects of CLA and a traditional approach (TA) on the attack performance of the outside hitter in volleyball.

Methods: Here, we report preliminary data on attack performance of U18 volleyball players (n = 6 + 6) that trained for 6 weeks according to CLA or a TA. Both groups trained zone 4 attacks with 3 common game block situations (line coverage, diagonal coverage, or space between the blockers) and did the exactly same amount of repetitions during the 6-week intervention period. However, in the CLA group the block situations were presented in a way that seemed random to the players while in the traditional group the block actions were previously known. Attack performance was tested three times: before the intervention (t1), after the intervention (t2), and in a follow-up test (t3). Factorial repeated measures ANOVA was used to compare between and within groups. Effect size (Cohen's *d*) was computed regarding between groups (at t1, t2, and t3) and within groups (t1–t2; t2–t3; and t1–t3).

Results: Successful Attack Actions (S_{AA}) was significantly higher in the CLA group ($p < 0.05$). At t1 S_{AA} was equal for both groups (46.29 ± 17.08). At t2, S_{AA} was higher in the CLA group (59.25 ± 25.70) than TA group (47.22 ± 15.39) with a moderate effect size ($d = 0.7$ SD), and at t3 S_{AA} was also higher in the CLA group (62.03 ± 26.07) than the TA group (48.14 ± 19.71) with a moderate effect size between groups ($d = 0.7$ SD).

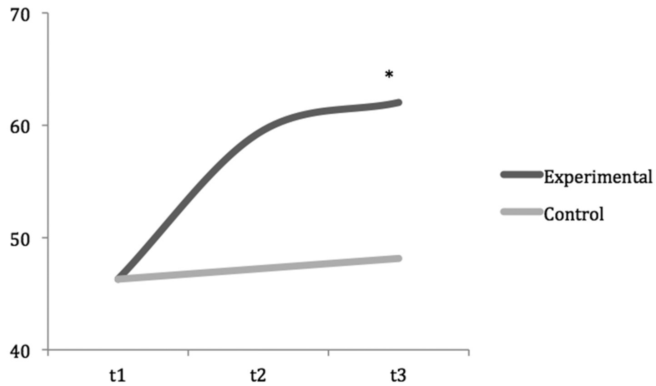


FIGURE 1: Mean of successful attack actions at pre-test (t1), post-test (t2), and follow-up test (t3).
* Significant differences between experimental and control groups ($p < 0.05$).

Although there were no significant difference within groups, in the CLA group the effect size from t1 to t2 was moderate ($d = 0.6$ SD), from t2 to t3 was small ($d = 0.1$ SD), and from t1 to t3 was moderate ($d = 0.7$ SD). In the TA group, the effect size from t1 to t2, t2 to t3, and t1 to t3 was small ($d = 0.06$ SD; $d = 0.05$ SD; and $d = 0,1$ SD, respectively).

Discussion and conclusion: The preliminary findings of this study reinforce that infusing constrained variability in task design as advocated by CLA allows volleyball players to exploit system degeneracy promoting superior effective goal achievement when compared to previously known tasks design (constraints).

REFERENCES

Chow, J. Y., Davids, K., Button, C., and Renshaw, I. (2016). *Nonlinear Pedagogy in Skill Acquisition an Introduction*. New York: Routledge.

Davids, K., Araújo, D., Hristovski, R., Passos, P., and Chow, J. Y. (2012). "Ecological dynamics and motor learning design in sport," in *Skill Acquisition in Sport: Research, Theory and Practice*, eds M. Williams and N. Hodges (New York: Routledge), 112–130.

Davids, K., Araújo, D., Shuttleworth, R., and Button, C. (2003). Acquiring skill in sport: a constraints-led perspective. *Int. J. Comput. Sci. Sport* 2, 31–39.

Renshaw, I., Araújo, D., Button, C., Chow, J. Y., Davids, K., and Moy, B. (2015). Why the constraints-led approach is not teaching games for understanding: a clarification. *Phys. Educ. Sport Pedagogy* 8989, 1–22. doi: 10.1080/17408989.2015.1095870

Complexity Matching in Ergometer Rowing

Ralf F. A. Cox[1], Ruud J. R. den Hartigh[1], Vivien Marmelat[2]

[1]*Department of Psychology, University of Groningen, Netherlands*
[2]*Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE, United States*
r.f.a.cox@rug.nl
j.r.den.hartigh@rug.nl
vmarmelat@unomaha.edu

Introduction: A relatively new finding relevant to sports is that optimal performance and well-trained behavior is reflected in patterns of high-frequency and low-amplitude fluctuations nested within low-frequency and high-amplitude fluctuations, called pink noise (e.g., Wijnants et al., 2009; Wijnants et al., 2012). Studies with cyclists, long-distance runners, skiers, and rowers, have consistently demonstrated pink noise in the athletes' performance time series (e.g., Hoos et al., 2014; Nourrit-Lucas et al., 2015). Moreover, recent studies revealed that higher-skilled rowers (Den Hartigh et al., 2015) and skiers (Nourrit-Lucas et al., 2015) demonstrated more prominent patterns of pink noise than less-skilled athletes. In addition to pink noise in individual performance, it has recently been shown that two people who perform a task together tend to match the fractal patterns of their behavioral time series. This effect called "complexity matching" reveals global coordination at multiple timescales, which is related to optimal information exchange between two systems. In recent years, complexity matching has been demonstrated in various areas of interpersonal interaction, for instance in people who oscillate hand-held pendulums while sitting next to each other (Marmelat and Delignières, 2012). Importantly, complexity matching is a multiscale phenomenon and cannot be attributed to local (i.e., short timescale) processes. This study investigates the presence of complexity matching in dyadic ergometer rowing. Following previous research outside the domain of sports, we predicted high correlation between the fractal patterns of two rowers who are rowing together and no correlation when they row alone. In addition, this should not be attributable to local correction processes.

Method: Sixteen competitive male rowers (M_{age} = 20.1, SD = 1.67), from three teams who trained together three times per week, were included in the study. Two rowing ergometers were used, placed next to each other, each equipped with a force sensor (Measurement Specialties, Inc.) registering the force on the handle at 100 Hz. Participants performed two rowing work-outs, one individually and one together with a randomly selected team member. During each session, they performed 550 rowing strokes at a preferred (individual or joint) rhythm. The drag factor was set at 120, corresponding to the usual workout resistance. After low-pass filtering (8 Hz), the raw force data was transformed into an inter-peak interval (IPI) time series of length 512. IPI represents the time interval between the moments at which maximal force was exerted in two subsequent

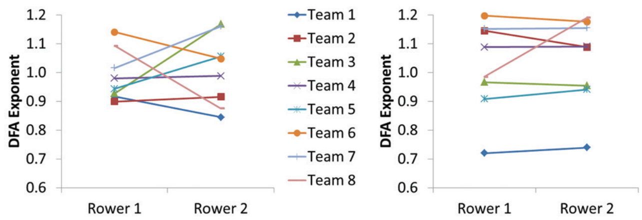


FIGURE 1: DFA exponents of the same rowers, identifiable by the colors, in the individual sessions (left panel) and dyadic sessions (right panel).

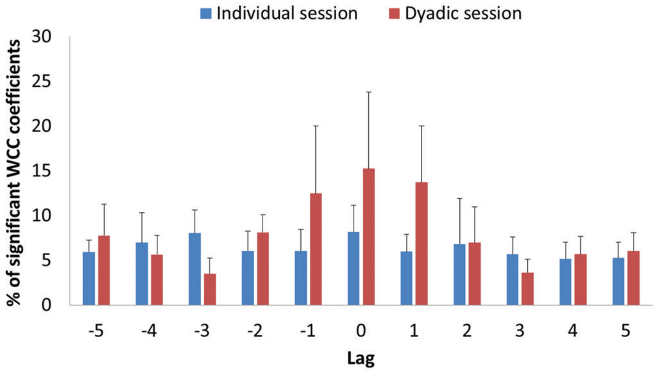


FIGURE 2: Percentage of significant windowed cross-correlations between the rowers' lagged IPI series in the individual (blue) and dyadic (red) sessions.

strokes. Evenly spaced detrended fluctuation analysis (DFA; Almurad and Delignières, 2016) was performed on the IPI time series. For pink noise DFA yields an outcome of 1, whereas for white noise it yields 0.5, and for Brownian noise it yields 1.5. In addition, windowed cross-correlation (WCC) analysis was conducted on the IPI time series for –5 to +5 lagged windows.

Results and discussion: The average DFA exponent of the IPI time series in the individual sessions was 1.00 (SD = 0.10; 95% CI = 0.95–1.05) revealing pink noise. Similarly, the average DFA exponent was 1.03 in the dyadic sessions (SD = 0.15; 95% CI = 0.96–1.11). These findings replicate and extend recent demonstrations of pink-noise performance fluctuations among skilled rowers (Den Hartigh et al., 2015). As can be seen in Figure 1, there was no significant correlation between the rowers' DFA exponents in the individual sessions, $r = 0.06$, $p = 0.89$, but a very strong correlation in the dyadic sessions, $r = 0.87$, $p < 0.01$. Note that excluding the distinct "purple" dyad from the analysis increased the correlation to $r = 0.99$, $p < 0.01$. Furthermore, the average percentage of significant zero-lagged WCCs was 15.23% and decreased with increasing lags (Figure 2). The percentage of significant WCC coefficients in the dyadic sessions was hardly higher than chance level. This indicates that the IPIs are largely locally independent, supporting the conclusion that there was not merely statistical matching resulting from local corrections within and between single rowing strokes. This finding extends the complexity matching hypothesis to the domain of sports. We conclude that interpersonal coordination in ergometer rowing likely takes the form of global adaptation between athletes. Joint rowing, therefore, should be considered as a multiscale phenomenon, which has important implications for research as well as training practices.

REFERENCES

Almurad, Z. M., and Delignières, D. (2016). Evenly spacing in detrended fluctuation analysis. *Physica A* 451, 63–69. doi: 10.1016/j.physa.2015.12.155

Den Hartigh, R. J. R., Cox, R. F. A., Gernigon, C., Van Yperen, N. W., and Van Geert, P. L. C. (2015). Pink noise in rowing ergometer performance and the role of skill level. *Motor Control* 19, 355–369. doi: 10.1123/mc.2014-0071 PMID:26559647

Hoos, O., Boeselt, T., Steiner, M., Hottenrott, K., and Beneke, R. (2014). Long-range correlations and complex regulation of pacing in long distance road racing. *Int. J. Sports Physiol. Perform.* 9, 544–553. doi: 10.1123/ijspp.2012-0334

Marmelat, V., and Delignières, D. (2012). Strong anticipation: complexity matching in interpersonal coordination. *Exp. Brain Res.* 222, 137–148. doi: 10.1007/s00221-012-3202-9 PMID:22865163

Nourrit-Lucas, D., Tossa, A. O., Zélic, G., and Delignières, D. (2015). Learning, motor skill, and long-range correlations. *J. Mot. Behav.* 47, 182–189. doi: 10.1080/00222895.2014.967655

Wijnants, M. L., Bosman, A. M., Hasselman, F., Cox, R. F. A., and Van Orden, G. (2009). 1/f scaling in movement time changes with practice in precision aiming. *Nonlinear Dynamics Psychol. Life Sci.* 13, 75–94. PMID:19061546

Wijnants, M. L., Cox, R. F. A., Hasselman, F., Bosman, A. M. T., and Van Orden, G. (2012). A trade-off study revealing nested timescales of constraint. *Front. Physiol.* 3:116. doi: 10.3389/fphys.2012.00116 PMID:22654760

Entropy and Emotional States in Marro-Game. A Gender Perspective

Assumpta Ensenyat[1], Pere Lavega[2], Veronica Muñoz[2], Gemma Espigares[1], Queralt Prat[2], Leonardo Machado[1], Aaron Rillo[2]

[1]Complex System and Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Catalonia, Spain

[2]Grup de recerca en Jocs Esportius (GREJE), National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Catalonia, Spain

aensenat@inefc.udl.cat

plavega@inefc.udl.cat

Introduction: While playing a game constraints derived from playing situations and internal emotional states may be expected. These may impact on the temporal regularity and predictability of motor action time-series. The aim of this study was to identify the influence of Marro-game on (a) the amount and the predictability of motor action, (b) the intensity of emotional states, and (c) to analyse whether emotional states had an association with entropy in men and women.

Methods: *Participants:* Participants were 150 undergraduate students (range = 19–24 years) recruited at the INEFC, University of Lleida.

Instruments and procedure: Participants took part in a class session during which they played the Marro-game, a well-known traditional game in Europe where two teams face each other. During the game, players can assume three different roles. They can be either at home (home) or outside home. When outside home they can be alive or prisoner. Participants from each class session were randomly distributed into four teams of eight participants (six men and two women). Each team played two 8-min Marro-games trials (M1 and M2) facing a different team each one. Between trials there was a 5-min recess pause during which each team agreed a collective strategy. Data collection was undertaken at the INEFC sports hall. Each game took place on a 15 m × 28 m surface. To assess motor activity, participants wore tri-axial accelerometers (ActiGraph GT3X+, ActiGraph LLC, Pensacola, FL, USA) on their waist. Accelerometers were programmed to sample movement at 100 Hz. After the game-trials, data were downloaded and processed using ActiLife 6.0 (ActiGraph, Pensacola, FL, USA) software. Recorded data points were integrated in one-second epochs yielding 960 (480 × 2) data points for each participant. Emotional state was assessed by means of the Games and Emotion Scale (GES) (Lavega et al., 2013). At the end of both trials, the students recalled the intensity level [1 (no emotion) to 7 (maximal intensity)] experienced for five basic emotions (joy, anger, sadness, fear, and rejection) (Bisquerra, 2003).

TABLE 1: Amount, structure of motor action during Marro-game, and emotional state during alive role.

	Men (n = 107)	Women (n = 44)	Between genders Δ Mean (95% CI)	p Value[a]	Effect size[b]
	M (SD)	M (SD)			
Motor action					
SampEn M1	0.74 (0.28)	0.69 (0.35)	0.04 (−0.06 to 0.15)	0.41	0.13
SampEn M2	0.72 (0.28)	0.58 (0.28)	0.13 (0.03–0.23)	0.01	0.46
VM (counts)	69536.0 (14715.3)	62725.6 (16893.3)	6810.4 (1369.27–12251.58)	0.01	0.43
VM (CPM)	4346 (919.7)	3920.3 (1055.8)	425.6 (85.58–765.72)	0.01	0.43
Emotional state (alive role)					
Joy	4.8 (1.5)	4.1 (1.6)	0.65 (0.09–1.2)	0.02	0.45
Anger	2.9 (1.7)	2.9 (1.7)	−0.03 (−0.64 to 0.57)	0.92	0.00
Sadness	1.4 (0.9)	1.6 (1.1)	−0.2 (-0.55 to 0.14)	0.24	-0.20
Fear	2.8 (1.7)	3.5 (1.7)	−0.68 (-1.3 to −0.06)	0.01	-0.41

CI, confidence interval; CPM, counts per minute; M1, Marro-game first trial; M2, Marro-game second trial; SampEn, sample entropy; VM, vector magnitude.
Data shown as mean (M) and standard deviation (SD).
[a]Wilcoxon test.
[b]Effect size according to Cohen (1992). Values 0.2–0.5 represent small differences, 0.5–0.8 moderate differences, and >0.8 large differences.

Data Analysis: Overall motor activity was expressed as vector magnitude (VM) in total counts and counts per minute. To assess the measure of regularity and predictability of motor activity time-series, sample entropy (SampEn) computations were carried out in MATLAB (The Mathworks, MA, USA) according to Monge Alvarez (2014) code with vector length, m of 2 and a tolerance, r of 0.2 (Richman and Moorman, 2000). Non-parametric tests were used for comparison between genders. Association between emotional intensity and entropy was analysed with Spearman correlation index. The significance alpha level was set at $p \leq 0.05$. Effect size was estimated according to Cohen (1992). Statistical data analysis was conducted using SPSS (Statistical Package for the Social Sciences, v17.0, SPSS Institute Inc., Chicago, IL, USA) software.

Results: Marro-game can be considered a vigorous physical activity with lower physical implication in women than men (Table 1). Although in M1 the temporal structure of motor action did not differ between genders, during M2 entropy was significantly lower in women. Emotional states were similar in women and men when they were at home or prisoners. At home, the intensity of happiness (M = 4.1, SD = 1.4) was greater than anger (M = 2.7, SD = 1.7) or than sadness (M = 1.5, SD = 1.0), fear (M = 1.5, SD = 1.1) or rejection (M = 1.5, SD = 1.1) which were low and similar. When they were prisoners the greater intensity was for anger (M = 4.6, SD = 1.7) and the lower was for fear (M = 1.3, SD = 0.7). When being in their alive role men felt happier and had less fear than women. No differences were observed for anger or sadness (Table 1). Women showed moderate negative significant associations between the intensity of fear ($r = -0.37$; $p = 0.016$) and sadness ($r = -0.33$; $p = 0.031$) perceived during the alive role and SampEn during M2. No association between basic emotions and entropy were observed in men.

Discussion and conclusion: Women and men may present differences in entropy as well as in emotional states when they assume different game roles. Negative emotions may impact on motor activity reducing motor behaviour complexity.

REFERENCES

Bisquerra, R. (2003). Educación emocional y competencias básicas para la vida [Emotional education and basic life competences]. *Revista de Investigación Educativa (RIE)* 21, 7–43.

Cohen, J. (1992). A power primer. *Psychol. Bull.* 112, 155–159. doi: 10.1037/0033-2909.112.1.155 PMID:19565683

Lavega, P., March, J., and Filella, G. (2013). Psychometric properties of the games and emotions scale (GES): an instrument for application in the context of physical educatioin and sport. *Revista de Investigación Educativa* 31, 151–166.

Monge Alvarez, J. (2014). *Research Master in Signal Theory and Bioengineering (Version 1st) [Computer Software]*. Valladolid, University of Valladolid.

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

Cardiorespiratory Fitness Testing in Low Active Adults. A Principal Component Analysis

Assumpta Ensenyat[1], Leonardo Machado[1], Gemma Espigares-Tribó[1], Alfonso Blanco[1], Natàlia Balagué[2]

[1]Complex System and Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Catalonia, Spain

[2]Complex System and Sport Research Group, National Institute of Physical Education of Catalonia (INEFC), University of Barcelona, Barcelona, Catalonia, Spain

aensenat@inefc.udl.cat

Introduction: The concept of cardiorespiratory coordination (CRC) has been recently used to refer to the mutual influence of cardiovascular and respiratory oscillations leading to spontaneous coordination (Balagué et al., 2016). According to the authors, the principal component analysis (PCA) allows examining the dimensionality of CRC and have detected that the number of PCs is sensitive to the effects of several training programs on physically active healthy males. However, to our knowledge this analysis has not yet been performed on low active/low fitness populations. The aims of this study were (a) to apply a PCA on the cardiorespiratory variables during a graded and maximal exercise test in low active adults (b) to identify whether there was an effect of intervention for the promotion of a healthy lifestyle or of gender on the cardiorespiratory dimensionality.

Methods: *Participants:* Participants were low active adults (12 men; 33 women) aged 36–55 [M = 45.2 (SD = 4.8) years] and engaged in a 4-months Primary Care intervention for the promotion of a healthy lifestyle (Ensenyat et al., 2017).

Instruments and Procedure: Before (T0) and after (T1), the lifestyle intervention participants performed a cardiorespiratory fitness test by means of a voluntary maximal graded exercise on a cycle ergometer (Monark 828E, Monark, Sweden). These tests were performed at a constant cadence of 60 rpm. After 2-min warm-up stage at 10 W the intensity of the workload increased 20 W every 2-min until participants were not able to maintain the pre-established cadence. During the graded exercise, oxygen uptake, and ventilation were measured using the Oxycon Mobile metabolic system (Oxycon Mobile, CareFusion, Germany). Gas calibrations were conducted before each test. Heart rate was measured using a Polar 610s chest heart rate monitor (Polar Electro YO, Kempele, Finland). Data collection was undertaken at the Laboratory Functional Assessment at INEFC-Lleida.

Data analysis: A PCA was performed on the time series of the following cardiorespiratory variables: heart rate (HR), expiratory volume (VE), end-tidal carbon dioxide pressure ($PETCO_2$), and end-tidal oxygen pressure ($PETO_2$) obtained during the graded maximal test. The number of PCs was determined by the Kaiser–Gutmann criterion, considering significant the PCs with eigenvalues ≥1.00 (Jolliffe, 2002). The optimal parsimony solution of the extracted PCs was obtained by the varimax orthogonal rotation criterion (Meglen, 1991). Since the first PC (PC_1) always contains the largest proportion of the data variance it was used for comparing the results among gender and pre/post intervention. Non-parametric *U* of Mann–Whitney tests were used to compare both genders and Wilcoxon test to compare pre and post intervention results. The significance alpha level was set at $p \leq 0.05$.

Results: Maximal workload, maximal oxygen consumption values, and the projections of the selected cardiorespiratory variables on PC_1 are shown in Table 1. No differences between men and women are observed with the exception of maximal load attained during the test. After the intervention, participants improved their maximal workload (men: Δmean = 20 W; IC 95% = 3.7–36.2 W; $p = 0.026$) (women: Δmean = 10.9 W; IC 95% = 4.7–17.1 W; $p = 0.001$). Neither VO_{2peak} nor the number of PCs changed significantly with the intervention. PCA revealed that at baseline two PCs were present in 78% of the participants (25 women and 10 men) while after the intervention only 62.2% of the participants (19 women and 9 men) showed two PCs, the rest (6 women and 1 man) changed from two to one PC.

Discussion and conclusion: In low active adults, the PCA performed on cardiorespiratory variables obtained during a graded maximal test did not reveal an effect of gender or lifestyle intervention on the projection of cardiorespiratory variables on PC even though the changes/differences of maximal workload. However, after the intervention 20% of participants reduced their number of PCs from two to one.

TABLE 1: Upper panel: Maximal workload and peak oxygen uptake in both genders attained during the graded maximal exercise test. Lower panel: projection of HR, VE, $PETCO_2$, and $PETO_2$ onto PC_1 in both genders.

	Time	Men ($n = 12$)		Women ($n = 33$)		p Value[a] men vs women
		M	*SD*	*M*	*SD*	
Maximal data						
$Workload_{max}$ (watts)	T0	157.7	37.07	106.4	22.61	0.000
	T1	177.7*	46.94	117.3*	19.25	0.000
VO_{2peak} (mL/kg/min)	T0	26.0	6.7	24.02	5.82	0.603
	T1	27.0	9.0	25.0	6.0	0.886

(*Continued*)

TABLE 1: (Continued)

	Time	Men (n = 12)		Women (n = 33)		p Value[a] men vs women
		M	*SD*	*M*	*SD*	
Projection onto CP_1						
HR (bpm)	T0	0.393	0.062	0.379	0.07	0.534
	T1	0.392	0.072	0.361	0.071	0.180
VE (L/min)	T0	0.405	0.069	0.381	0.072	0.279
	T1	0.384	0.065	0.355	0.057	0.088
$PETCO_2$ (kPa)	T0	0.058	0.153	0.064	0.179	0.950
	T1	0.087	0.176	0.035	0.211	0.207
$PETO_2$ (kPa)	T0	0.249	0.083	0.242	0.086	0.790
	T1	0.191	0.153	0.241	0.115	0.247

CP_1, principal component 1; HR, heart rate; $PETCO_2$, end-tidal carbon dioxide pressure; $PETO_2$, end-tidal oxygen pressure; T0, before the intervention; T1, after the intervention; VE, expiration volume; VO_{2peak}, oxygen consumption peak.
Data shown as mean (*M*) and standard deviation (*SD*).
[a]Mann–Whitney test.
[*]Significant differences in relation to baseline data (T0). $p < 0.05$, Wilcoxon test.

REFERENCES

Balagué, N., Gonzalez, J., Javierre, C., Hristovki, R., Aragonés, D., Alamo, J., et al. (2016). Cardiorespiratory coordination after training and detraining. A principal component analysis approach. *Front. Physiol.* 7:35. doi: 10.3389/fphys.2016.00035 PMID:26903884

Ensenyat, A., Espigares-Tribo, G., Machado, L., Verdejo, F., Rodriguez, R., Serrano, J., et al. (2017). Metabolic risk management, physical exercise and lifestyle counselling in low-active adults: controled randomized trial (BELLUGAT). *BMC Public Health* 17:257. doi: 10.1186/s12889-017-4144-8

Jolliffe, I. (2002). *Principal Component Analysis*. New York, NY: Springer.

Meglen, R. (1991). Examining large database: a chemometric approach using principal component analysis. *J. Chemometr.* 5, 163–179. doi: 10.1002/cem.1180050305

Development of an Exhausting Exercise Model in Young Rats: Effect on Immune System

Sheila Estruel-Amades[1,2], Marta Périz[1,2], Mariona Camps-Bossacoma[1,2], Malen Massot-Cladera[1,2], Ignasi Azagra[1,2], Àngels Franch[1,2], Francisco Pérez-Cano[1,2], Margarida Castell[1,2]

[1]*Faculty of Pharmacy and Food Science, Department of Biochemistry and Physiology, Section of Physiology, University of Barcelona, Barcelona, Spain*
[2]*Nutrition and Food Safety Research Institute, University of Barcelona (INSA-UB), Santa Coloma de Gramanet, Spain*
margaridacastell@ub.edu

Introduction: While moderate exercise induces many beneficial effects on human health (Nimmo et al., 2013), an intense and exhaustive exercise could induce adverse effects on the immune system, leading to an increased risk of upper respiratory tract infections (URTI) (Gleeson, 2007; Kruijsen-Jaarsma et al., 2013). In this context, animal models in which an exercise-derived immunodepression can be reproduced are very limited. The aim of this study was to establish immune markers of immunodepression induced by exhausting exercise in both the rat systemic and mucosal immune system.

Methods: Male and female young (4-week-old) Wistar rats were trained, for 4 weeks, on a treadmill device (Panlab LE8700) that forced animals to run in controlled conditions. A similar group of rats was kept in sedentary conditions throughout the study (with only spontaneous activity inside the cage). The exercise procedure included 2 days of habituation to the treadmill, followed by a 2-week pre-training period with a gradual increase of speed and duration, starting with a 10 min training session at 8 cm/s (4.8 m/min) increasing to a 25 min session at 42 cm/s. In the last 2 weeks, animals were trained twice a day, running 30 min at 50 cm/s (30 m/min) in each session. On the last day, animals were submitted to a fatigue test, starting with an initial speed of 8 cm/s with a gradual increase of 3 cm/s every minute. The animal was considered exhausted when it could not maintain its normal position. The procedure was approved by the Ethical Committee for Animal Experimentation of the University of Barcelona (ref. 9257). Oxygen consumption was measured at the beginning, in the middle and during the exhausting test by indirect calorimetry. Feces were collected weekly from the beginning of the study. At the end of the study, gastrocnemius muscle, heart, and lymphoid tissues such as thymus and spleen, were dissected and weighed. Spleen lymphocytes were isolated and their composition evaluated by flow cytometry. In addition, cytotoxic activity of natural killer (NK) cells was evaluated by flow cytometry using K562 cells as target cells. To check the status of mucosal immunity, fecal immunoglobulin A (IgA) was quantified by an enzyme-linked immunosorbent assay (ELISA).

Results: Oxygen consumption quantified at the beginning of the procedure showed similar values for both runner and sedentary groups, which was about 27 mL/min/kg body weight (BW) (±0.741 SEM, standard error of the mean) ($p = 0.447$). On day 13, the oxygen consumption was 39% higher in runners than in sedentary rats ($p = 0.002$). During the fatigue test, oxygen consumption in runners was about 51.0 ± 2.07 mL/min/kg BW, which was significantly higher than that obtained from the sedentary rats (29.76 ± 1.11 mL/min/kg BW) ($p = 0.003$). In the fatigue test, male runner rats achieved a maximum speed of about 106.40 ± 3.20 cm/s, whereas female rats ran up to 126.429 ± 5.214 cm/s. Training produced a significant increase in the gastrocnemius muscle relative weight of the runner rats, achieving values of 6.13 g/kg BW (±0.093 g/kg BW) ($p = 0.003$), which were 10% higher than that in the sedentary group (5.57 ± 0.452 g/kg BW). Similarly, relative heart weight increased by up to 11% in runners ($p = 0.012$), reaching values ranging between 3.38 and 4.31 g/kg BW (3.78 ± 0.092 vs 3.34 ± 0.060 g/kg BW in sedentary rats). Regarding immune status, runner rats showed a lower relative thymus weight (2.78 ± 0.136 g/kg BW) than the sedentary group (3.32 ± 0.130 g/kg BW) ($p = 0.010$). Likewise, the relative spleen weight in runners (2.86 ± 0.135 g/kg BW) was lower than that in sedentary rats (3.39 ± 0.101 g/kg BW) ($p = 0.003$). The analysis of lymphocyte subsets in the spleen showed no changes induced by training in the main subset proportions: B and T cells (including TCR$\alpha\beta$+ -Th and Tc-, TCR$\gamma\delta$+ and NKT lymphocytes). However, the proportion of NK cells, which was about 10.96 ± 0.423% in sedentary rats increased by up to 12.43 ± 0.552% in runners ($p = 0.021$). When considering the cytotoxic activity of these cells, in sedentary rats the killer activity was about 45.34 ± 0.587% and that in runners was significantly lower (42.75 ± 0.687%) ($p = 0.012$). Finally, a mucosal immunity study revealed that fecal IgA decreased with training, with levels of 62.13 ± 1.22 ng/mg feces in sedentary rats and significantly lower levels in runner animals (36.23 ± 4.69 ng/mg feces, $p = 0.027$).

Discussion and conclusion: The increase training exercise applied in rats for 4 weeks followed by a fatigue test affected the function of the immune system. This can be quantified by a decreased activity of NK cells, which play a key role in the systemic innate immunity. In addition, there was a decrease in the intestinal IgA content, which constitutes a biomarker of immune status at mucosal sites. These results show two biomarkers modified by training and a fatigue test that could explain the immunodepression observed in humans (Kruijsen-Jaarsma et al., 2013). This model could be used to apply strategies that decreased these harmful effects on the immune system induced by exhausting exercise.

Acknowledgements

This study was supported by a grant from the Spanish Ministry of Economy and Competitiveness (AGL2016-76972-R, AEI/FEDER, UE).

REFERENCES

Gleeson, M. (2007). Immune function in sport and exercise. *J. Appl. Physiol.* 103, 693–699. doi: 10.1152/japplphysiol.00008.2007 PMID:17303714

Kruijsen-Jaarsma, M., Révész, D., Bierings, M. B., Buffart, L. M., and Takken, T. (2013). Effects of exercise on immune function in patients with cancer: a systematic review. *Exerc. Immunol. Rev.* 19, 120–143.

Nimmo, M. A., Leggate, M., Viana, J. L., and King, J. A. (2013). The effect of physical activity on mediators of inflammation. *Diabetes Obes. Metab.* 15, 51–60. doi: 10.1111/dom.12156 PMID:24003921

Corner Kicks in High Performance Football Analyzed through Dynamic Applications Integrated in the Training to Improve the Efficacy

Daniel Fernández and Oleguer Camerino

Laboratorio de Observación de la Motricidad. National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
danifh6@gmail.com

Introduction: Recently, it has been made to apply concepts from dynamical systems and ecological dynamics theory to the study of emergent game structure and tactical patterns in team sport (Davids et al., 2014). In this regard, understanding profiles of play and how they are learnt cognitively in team sports is a new and interesting approach to the optimization of effective performance (Balagué et al., 2017). Several models have been developed to describe the game dynamics as focused on decision-making models (Vilar et al., 2012). In football, the opportunity to scoring may be shaped by constraints, such as the locations of the ball, the goal, nearest defenders, ball's trajectory, motivation, and fatigue. The aim of this study is to analyze the factors of the game dynamics that affect the effectiveness of the tactic-technique actions of the corner kicks in professional football. We want to design new training methodologies that can influence the variables on this set piece and that could affect to the subsequent achievement of the goal and thus, improve its efficacy.

Methods used: The study uses observational methodology to record the wide variety, that observational methods are the best way of revealing relationships and behaviors in the dynamics of game in team sports (Fernández et al., 2009; Camerino et al., 2011).

Participants: The 110 goals scored by the teams that belong to the first Spanish division during the 2016–2017 season are going to be observed and selected from InstatScout® web platform.

Observation instruments: The observation instrument chosen for the present study was the SOCFO-1 (see Table 1). SOCFO-1 is multidimensional in nature and has the following structure of criteria, and categories were chosen because its criteria or dimensions staying in line with the objectives of this study: corner kick.

Recording instrument: Goals sequences were coded using LINCE (v.1.2.1) (Gabin et al., 2012; Hernández Mendo et al., 2014). The observer introduces all the codes corresponding to each criterion and categories. When changes are observed in any of these criteria and category the video is paused and the corresponding data are entered into the observational record (Camerino et al., 2011).

Data analysis software: Three programs were used: (a) SPSS 21.0 for a preliminary analysis of the data; (b) THEME v. 6 software package (Magnusson et al., 2016) for T-pattern detection.

Results: After having studied the results, we have identified that the majority of goals came from two actions. The main one is direct passing to the box and shooting to score. The other one is almost the same, except that previously there is a short pass near the corner.

Corners kicked with the natural foot to zone 8 (see Figure 1), causes the trajectory of the ball to be opened, keeping the ball away from the defenders and making the kick easier for the attackers and thus, increase corner's efficacy. Best way of finishing the corner kick is with a dynamic movement hitting ball with head.

Discussion and conclusion: Even though in every match there are thrown a highest number of corners kicks, the effectiveness in relation to the goal is limited. However, this kind of set piece is decisive to the scoreboard (Maneiro, 2014). Instead of the classic fractional process of some training methodologies (Prieto, 2008), we would not try to separate the actions or components of the sport respecting their primordial synergies and perception-action cycles. In the learning processes it's proposed to start from the basic integral synergies to grow in the scale of coordinating complexity through the manipulation of constraints (Balagué et al., 2017). This essay considers a different point of view on training set pieces, similar to a football match, with its physical and psychological exigencies. We suggest to integrate the training of the corner kicks during all exercises into the microcycle, as it could be a rondo, creating similar situations of tiredness to the first minutes to the match, or physical and psychological tiredness as in attack—defense transition exercises, but not working them the last day before the match without opposition and tiredness.

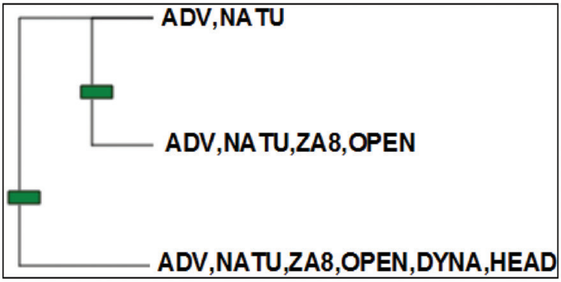
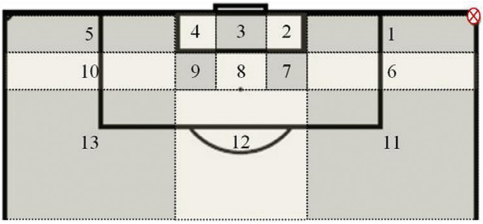


FIGURE 1: More representative T-patterns dendogram of corner kicks.

TABLE 1: Criteria, categories, and used definitions.

Criteria	**Category**	**Description**
Score (SCO)	ADV	Advantage to the team analyzed
	DRA	Draw (same goals)
	DISA	Disadvantage to the team analyzed
Laterality of kick (LAT)	NATU	Nature. Right footed kicker serves the corner from the right side/left footed kicker serves the comer from the left side
	SWIT	Switched. Right footed kicker serves the comer from the left side/left footed kicker serves the corner from the right side
Zone of action (ZOA)	ZA1	
	ZA2	
	ZA3	
	ZA4	
	ZA5	
	ZA6	
	ZA7	
	ZA8	
	ZA9	
	ZA10	
	ZA11	
	ZA12	
	ZA13	
Ball's trajectory (BTR)	OPEN	Opened
	CLOS	Closed
	OTHE	Other trajectories: passes on the ground and parallel trajectories
Types of finishing (TFT)	STAT	Static. The attacking player scores without movement
	DYNA	Dynamic. The attacking player scores in movement
Way of finishing (FIN)	FEET	Finishing with the feet
	HEAD	Finishing with the head
	OTFI	Finishing with other admitted parts of the body

REFERENCES

Balagué, N., Torrents, C., Hristovski, R., and Kelso, J. A. S. (2017). Sports science integration: an evolutionary synthesis. *Eur. J. Sport Sci.* 17, 51–62. doi: 10.1080/17461391.2016.1198422

Camerino, O., Chaverri, J., Anguera, M. T., and Jonsson, G. K. (2011). Dynamics of the game in soccer: detection of T-patterns. *Eur. J. Sport Sci.* 12, 216–224. doi: 10.1080/17461391.2011.566362

Davids, K., Hristovski, R., Araújo, D., Balagué, N., Button, C., and Passos, P. (2014). *Complex Systems in Sport*. London: Routledge.

Fernández, J., Camerino, O., Anguera, M. T., and Jonsson, G. K. (2009). Identifying and analyzing the construction and effectiveness of offensive plays in basketball by using systematic observation. *Behav. Res. Methods* 41, 719–730. doi: 10.3758/BRM.41.3.719 PMID:19587184

Gabin, B., Camerino, O., Anguera, M. T., and Castañer, M. (2012). Lince: multiplatform sport analysis software. *Procedia Soc. Behav. Sci.* 46, 4692–4694. doi: 10.1016/j.sbspro.2012.06.320

Hernández Mendo, A., Castellano, J., Camerino, O., Jonsson, G., Blanco Villaseñor, A., and Anguera, M. T. (2014). Programas informáticos de registro, control de calidad del dato, y análisis de datos. *Revista de psicología del deporte* 23, 111–121.

Magnusson, M. S., Burgoon, J. K., and Casarrubea, M. (eds) (2016). *Discovering Hidden Temporal Patterns in Behavior and Interaction: T-Pattern Detection and Analysis with THEME*. New York, NY: Springer-Verlag.

Maneiro, R. (2014). *Análisis de las acciones a balón parado en el fútbol de alto rendimiento: saques de esquina y tiros libres indirectos. Un intento de identificación de variables explicativas*. Tesis doctoral no publicada, Universidad de A Coruña, A Coruña, España.

Prieto, A. (2008). *Estudio técnico-táctico de las acciones a balón parado. Revista digital Fútbol-táctico.Com*. 18.

Vilar, L., Araújo, D., Davids, K., and Button, C. (2012). The role of ecological dynamics in analysing performance in team sports. *Sports Med.* 42, 1–10. doi: 10.2165/11596520-000000000-00000 PMID:22149695

Handball Different Coordination Patterns during a World Championship

José Flores-Rodríguez, Gonzalo Ramírez-Macías

Universidad de Sevilla, Sevilla, Spain
josefloresrodriguez@live.com

Introduction: In team sports, players have the ability to influence other players' behaviour, originating team synergies. These are related to the collective attunement to share affordances, which form coordination patterns of a team (Silva et al., 2013). Araujo et al. (2015) highlight four key properties of team synergies: (1) dimensional compression, the state of the system can be summarized by the order parameter; (2) reciprocal compensation, if one player contributes more or less in his expected role, other team elements should adjust their contribution; (3) interpersonal linkages, referred to specific contribution of each element to a group task, and (4) degeneracy, referred to how one synergy can be transformed into another at specific moments. To understand the emergent dynamic pattern during the game, it is necessary to study the collective parameters that may express the collective state of the team throughout time (Travassos et al., 2010). The objective of our study is to know coordination patterns of a handball team under specific constraints: time and score game. For this purpose, we analyzed some collective parameters of the positional attack: plays, number of passes, and termination mode.

Methods: Observational methodology has been proved effective in the analysis of the interactions that araised in team sports (Castañer et al., 2016) letting us know the different coordination patterns during competition. Our study analyzed the coordination pattern of the Male Spanish Handball Team (SPA) during 4 matches (rounds of 16, quarterfinals, semifinal, and third place's match) at the World Championship Catar 2015. Positional attacks, when both teams in numerical equality (7 vs 7) were coded using an *ad hoc* observation instrument (Table 1), Kappa value for interobserver was 0.81. To know team's synergies and coordination patterns, we performed lag sequential analysis of behaviours using GSEQ v5.1.15 (Bakeman and Quera, 2011) followed by polar coordinate analysis HOISAN v1.3.6.1 (Hernández-Mendo et al., 2012) that shows statistically significant associations (excitatory or inhibitory) between the focal and conditional behaviours. The polar coordinate maps show quantitative (length of vector) and qualitative (quadrant I, II, III, or IV) association: quadrant I, focal and conditional are mutually excitatory; quadrant II, focal behavior is inhibitory and conditional behavior is excitatory; quadrant III, focal and conditional behaviors are mutually inhibitory, and quadrant IV, focal behavior is excitatory and conditional behavior is inhibitory (Castañer et al., 2016).

TABLE 1: Observation instrument.

Criterion	Category
Time	Minute of positional attack beginning: from 0′00″ to 50′00″ (SB0)/from 50′01″ to the end of the match (SB6)
Score	Score at the positional attack beginning: Spain leads (WIN)/ Spain loses (LOS)/tied (EMP)
Play	When 3.3 offensive system left, right, and centre back changes their position (CHA)/when left or right wing change their position to become line player (2PV)/when 3:3 offensive systems transform into 2:4 system after left, right, or centre back become line player (2CU). Individual action (LIB)
Number of passes	Number of passes made before attack ends, after positional attacks increase rhythm: zero (PS0)/one (PS1)/two (PS2)/three (PS3)/four (PS4)/five (PS5)
Termination mode	The way positional attacks end: shoot beyond the 9 m line (L9M)/shoot between 6 and 9 m (L69)/shoot or pass to line player (PVT)/right or left wing shoot (LEX)/left, right or centre back made a shoot from 6 m (REG)/turn over (not included passes to line player) (ERR)

Results: We will discuss the vectors with length >1.96 ($P < 0.05$) in quadrant I (upper right quadrant of the map) representing mutually excitatory associations. For the focal behaviour we used the combination of two categories, one related to time and the other related to score when attacks began: (SB0_WIN, SB6_WIN, SB0: LOS, SB6_LOS, SB0_EMP, and SB6_EMP). And for the conditional behaviours we used the rest of the observation instruments (Figure 1). When SPA was leading, and the focal behaviour SBO_WIN (attacks beginning within the first 50 min, maps 1–3) show a mutually excitatory association: 2CU, CHA, PS3, and L9M. Nevertheless SB6_WIN (attacks within the last 10 min and overtime, maps 4–6) show a mutually excitatory association: PS2, PS4, and PVT. When SPA was losing, and the focal behaviour SB0_LOS (attacks beginning within the first 50 min, maps 7–9) show a mutually excitatory association: 2CU, PS1, LEX, and L69. Nevertheless SB6_LOS (attacks within the last 10 min and overtime, maps 10–12) show a mutually excitatory association: 2PV, LIB, PS3, and L9M. In focal behaviour SB0_EMP (when scores were tied within the first 50 min, maps 13–15) show a mutually excitatory association: PS3. Nevertheless SB6_EMP (scores were tied within the last 10 min and overtime, maps 16–18) show a mutually excitatory association: 2PV and REG.

Discussion and conclusion: Our findings show that synergies and coordination pattern change into another at specific moments of the matches (Araújo and Davids, 2016).

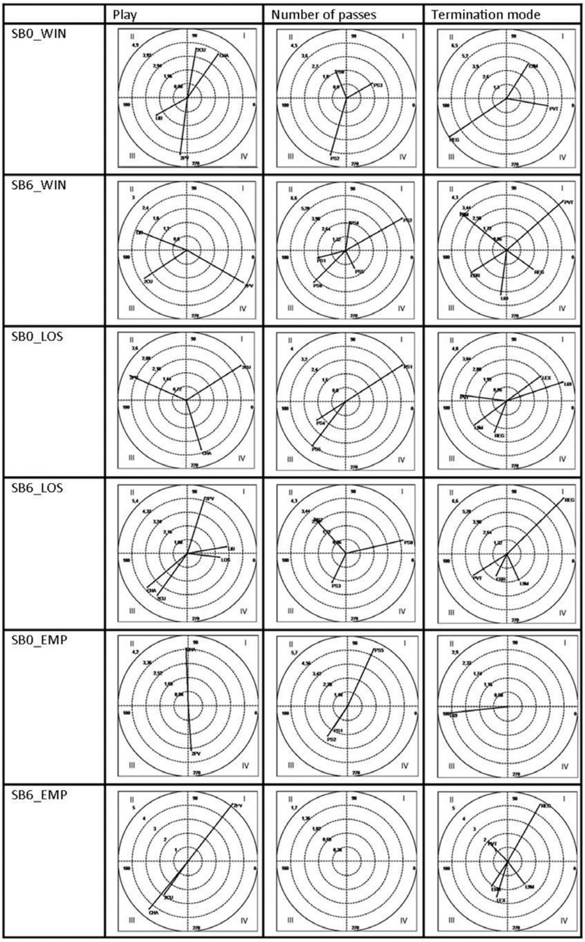


FIGURE 1: Polar coordinate maps 1–18.

Collective parameters studied (plays, number of passes, and termination mode) are modified according to focal behaviour analyzed (time and score). The ability to anticipate under what constraints emerge certain coordination patterns is a powerful tool for a coach. Deeper understanding of player's interactions with environment may allow coaches to make more appropriate decisions on training and competition management (Travassos et al., 2010). Through training process players can improve their capacity to perceive collective affordances (Fajen et al., 2009) and also enhance their ability to actively create it (Araujo et al., 2015). To achieve better performance it is necessary to improve, avoid, or create new coordination patterns.

REFERENCES

Araújo, D., and Davids, K. (2016). Team synergies in sport : theory and measures. *Front. Psychol.* 7:1449. doi: 10.3389/fpsyg.2016.01449

Araujo, D., Passos, P., Esteves, P., Duarte, R., Lopes, J., Hristovski, R., et al. (2015). The micro-macro link in understanding sport tactical behaviours: integrating information and action at different levels of system analysis in sport. *Mov. Sport Sci. Sci. Mot.* 89, 53–63. doi: 10.1051/sm/2015028

Bakeman, R., and Quera, V. (2011). *Sequential Analysis and Observational Methods for the Behavioral Sciences*. Cambridge: Cambridge University Press.

Castañer, M., Barreira, D., Camerino, O., Anguera, M. T., Canton, A., and Hileno, R. (2016). Goal scoring in soccer: a polar coordinate analysis of motor skills used by Lionel Messi. *Front. Psychol.* 7:806. doi: 10.3389/fpsyg.2016.00806

Fajen, B. R., Riley, M. A., and Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *Int. J. Sport Psychol.* 40, 79–107.

Hernández-Mendo, A., López-López, J. A., Castellano, J., Morales-Sánchez, V., and Pastrana, J. L. (2012). HOISAN 1. 2 : programa informático para uso en metodología observacional. *Cuadernos de Psicologia del Deporte* 12, 55–77. doi: 10.4321/S1578-84232012000100006

Silva, P., Garganta, J., Araújo, D., Davids, K., and Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Med.* 43, 765–772. doi: 10.1007/s40279-013-0070-9

Travassos, B., Araújo, D., Correia, V., and Esteves, P. (2010). Eco-dynamics approach to the study of team sports performance. *Open Sports Sci. J.* 3, 56–57. doi: 10.2174/1875399×01003010056

Serve Is Not an Advantage in Elite Men's Badminton

Miguel-Ángel Gómez[1], Adrián Cid[2], Fernando Rivas[1,3], Luis-Miguel Ruiz-Pérez[1], Jaime Sampaio[4]

[1]Faculty of Physical Activity and Sport Sciences, Technical University of Madrid, Spain
[2]Faculty of Physical Activity and Sport Sciences, European University of Madrid, Spain
[3]Spanish Badminton Federation, High Performance Center, Madrid, Spain
[4]Department of Sport Sciences, University of Trás-os-Montes e Alto Douro, Vila Real, Portugal
miguelangel.gomez.ruano@upm.es

Introduction: Badminton is a complex and dynamic sport where the players' actions require quick decision-making and actions trying to disrupt the opponent's balance, while trying to lead the rallies (Chow et al., 2014). Specifically, the net-racket sports are characterized by alternating the possession between opponents (i.e., one vs one confrontations) that occur during a rally. Then, in badminton each rally starts with a serve representing the starting point of this dynamic interaction that may disrupt the receiver's balance and create an advantage for the server during the rally. Recently, Bialik (2016) presented the average advantage when serving in the Olympic racket sports with tennis as the sport that has the greatest serving advantage (>56%) and the lowest values were identified in beach volleyball (<35%). Specifically, the serving advantage in badminton was close to a slight advantage (52 and 55% for men and women, respectively). However, the server's advantage (i.e., the probability of winning the rally with the serve) has not been previously studied in the badminton available research (Abián et al., 2014; Laffaye et al., 2015). Then, this analysis may show the complexity of winning a rally for the server or the receiver according to the number of strokes in each rally and the type of serve used. In this sense, it may be expected that the advantage of the serve is lower as the rally time duration increases, and then the unpredictability and complex dynamics. Therefore, the aim of this study was to identify the serve and reception effectiveness according to the match outcome and the type of serve.

Methods: The sample was composed by 19 matches played by the medalists from the 2016 men's singles Olympic Games (Rio, Brazil). The final sample included the analysis of 1,475 rallies. The variables studied in the analysis were: win/lose and serve type (IV) and point outcome (winner, forced error, or unforced error) according to the complex of game (C1: serving and C2: receiving) as DV. The analyses were carried out using the video analysis program (Dartfish). To do so four trained observers gathered the variables showing good and very good inter-rater reliability values (Kappa: >0.81; $r > 0.86$; ICC: >0.85, and SEM: <0.46). The crosstabs commands were used to study the relationships (Pearson's Chi-square test) between point outcome and match outcome and type of serve. Effect sizes (ES) were estimated by calculating the Cramer's *V* test. The analyses were done using the statistical software IBM SPSS statistics for Windows, version 20.0 (Armonk, NY, USA: IBM Corp.), and the significance level was set to $p < 0.05$.

Results: The descriptive analysis was carried out to show the point's outcome according to the number of strokes (see Figure 1). It is needed to understand that C1 complex includes the odd strokes (1, 3, 5, etc.) and C2 complex includes the even strokes (2, 4, 6, etc.). Accordingly, the first and second strokes produce 85.7 and 60.7% of unforced errors, respectively, decreasing the percentage of unforced errors as the rally goes on. The serve advantage was of 49 (C1) and 51% for serving advantage (C2). In addition, these values were of 46.9 (C1) and 53.1% (C2) for winners and 52.8 (C1) and 47.2% (C2) for losers. The results differentiating winning and losing (see Table 1) showed that to win a match the players should perform more winners and less forced and unforced errors than the opponent when serving. In addition, the results of serve type showed that the most used is the backhand short serve (91.9%). The relationships between serve type and point outcome showed that the use of backhand flick serve produces more C2 winners and less C1 forced errors. In addition, the use of backhand short serve increases the C1 forced errors and less C2 winners. Finally, the use of forehand short serve generates more C2 winners and less C1 unforced errors.

Discussion and conclusion: The main results of this study is that in badminton there is a null serving advantage. As Bialik (2016) argued it can be considered a way to get the point started. In particular, the results obtained by the server and receiver when winning and losing showing a surprising trend with winners obtaining less than 50% of efficacy when using the serve but with better values when receiving and the opposite for losing players. This results may point out the complexity of badminton sport with constant actions trying to avoid clear hits and put the birdie where the opponent cannot (Bialik, 2016). On the other hand, these results may show that winners show more conservative serving tactics (C1) but take more risks during the C2 complex (Abián et al., 2014). Specifically, the results reinforce the importance of using the less risky serve that may allow the player to lead the point (Chow et al., 2014). Then, the use of backhand short serve is the best way to do so reducing the options to the opponent to disrupt the prefixed tactic of the server. Also, these results may show more defensive and physical demands in elite badminton with taller and stronger players who may attack and hit the birdie from most of the zones of the court. Then, the complex structure of badminton rallies is more conservative in terms of serves and first strokes.

FIGURE 1: Distribution of point's outcome according to the number of strokes.

TABLE 1: Frequency distribution (n and %) of point outcome according to serve (C1) or receive (C2) for win or lose the match and the type of serve used. Note: †Residual adjusted values greater than |1.96|.

	Match outcome					
	Win		Lose		Total	
Point Outcome	N	%	N	%	N	%
C1 Winner†	161	24.5	89	10.9	250	16.6
C1 Unforced error†	93	14.2	195	24.2	288	19.2
C1 Forced error†	54	8.2	145	17.7	199	13.2
C2 Winner	124	18.9	143	17.5	267	17.8
C2 Unforced error	151	18.4	143	17.5	294	19.6
C2 Forced error	103	15.7	101	12.3	204	13.6
	χ^2	p	ES			
	86.48	0.001	0.24			

	Type of serve									
	BF		BSS		FF		FSF		Total	
Point Outcome	N	%	N	%	N	%	N	%	N	%
C1 Winner	17	6.8	226	90.4	2	0.8	5	2.0	250	16.9
C1 Unforced error†	18	6.2	271	93.1	1	0.3	1	0.3	291	19.7
C1 Forced error†	2	1.0	192	96.5	2	1.0	3	1.5	199	13.5

(*Continued*)

TABLE 2: (*Continued*)

	BF		BSS		FF		FSF		Total	
Point Outcome	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**	**N**	**%**
C2 Winner†	17	6.4	237	88.8	2	0.7	11	4.1	267	18.1
C2 Unforced error	11	4.2	247	93.6	0	0.0	2.4	4	264	17.9
C2 Forced error	15	7.4	183	89.6	2	1.0	4	2.0	204	13.8
Total	80	5.5	1356	91.9	9	0.6	30	2.0	1475	100
	χ^2	P	ES							
	28.25	0.001	0.08							

Acknowledgement

This study was supported by the Ministry of Economy and competitiveness of Spain with the project “Estudio de los complejos de juego y los perfiles de rendimiento en bádminton de élite COMPLEXBAD” (DEP2015-67231-R).

REFERENCES

Abián, P., Castanedo, A., Feng, X. Q., and Abian-, J. S. J. (2014). Notational comparison of men’s singles badminton matches between Olympic Games in Beijing and London. *Int. J. Perform. Anal. Sport* 14, 42–53. doi: 10.1080/24748668.2014.11868701

Bialik, C. (2016). *Serving is a Disadvantage in Some Olympic Sports. FiveThirtyEight*. Available at: https://fivethirtyeight.com/features/serving-is-a-disadvantage-in-some-olympic-sports/

Chow, J. Y., Seifert, L., Hérault, R., Chia, S. J. Y., and Lee, M. C. Y. A. (2014). Dynamical system perspective to understanding badminton singles game play. *Hum. Mov. Sci.* 33, 70–84. doi: 10.1016/j.humov.2013.07.016

Laffaye, G., Phomsoupha, M., and Dor, F. (2015). Changes in the game characteristics of a badminton match: a longitudinal study through the olympic game finals analysis in men’s singles. *J. Sports Sci. Med.* 14, 584–590. PMID: 26335338

Which Serve Variables Predict Its Efficacy in the U-21 Volleyball World Championship?

C. Fernández-Echeverría[1], J. González-Silva[1], M. Conejero[1], F. Claver[2], M. P. Moreno[1]

[1]*Didactic and Behavioural Analysis Research Group, Faculty of Sport Sciences, University of Extremadura, Badajoz, Spain*

[2]*Faculty of Health Sciences, Miguel de Cervantes European University, Valladolid, Spain*

cafernandeze@unex.es

Introduction: As a finalist action, the serve has gone from being the action that starts the game to be considered the first attack weapon (Quiroga et al., 2010). Therefore, the serve is one of the most correlated with victory actions and act as a predictor of success in volleyball (Silva et al., 2014). Because of the importance of this action in the game, the objective of the investigation is to determine the serve variables that predict its efficacy.

Methods: *Sample:* The study sample was comprised of 2,238 serve actions, corresponding to the observation of four, the best teams participating in the Men's World Championship, U-21 category, in 2015.

Variables: The following variables were considered in our study: *in-game role of the server,* setter, receiver-attacker, middle attacker, opposite; *serve zone*, zone 1, zone 6, zone 5 (Quiroga et al., 2012); *serve type*, jump float serve, jump serve (García-de-Alcaraz et al., 2016); *serve direction*, parallel, mid cross-court, long cross-court; *serve efficacy,* the serve effectiveness were divided into three categories according to the Data Volley System (Data Project, Bologna, Italy, release 2.4.0): error (=), serve-continuity (+), direct point (#).

Statistical Analysis: The multinomial logistic regression model was used. Prior to the regression test, a multicollinearity analysis was performed in order to avoid using intercorrelated variables. After this test, no variables were excluded from the model because any multicollinearity was not present.

Results: Table 1 shows the predictive analysis of the reference category "serve error," of the variable serve efficacy, compared with the rest of categories (positive serve and serve point). In the comparison between serve error and positive serve, it was obtained that, when the serve was made by the opposite player (OR = 0.607), instead of the receiver player, the serve efficacy decreases, by decreasing the positive serve, instead of the service error. In addition, when the serve is made from zone five (OR = 0.498), instead of from zone one, there is a decrease in serve efficacy, by decreasing the positive serves, instead of the serve errors. Finally, in this comparison, when a float serve was made (OR = 3,810), instead of a powerful jump serve, the serve efficacy is increased, with the increase of positive serves, instead of serve error. In comparison between the serve error and the serve point, the results showed that, when the serve is performed by the setter (OR = 2.2265) or by the center (OR = 2.392), instead of the receiver player, it increased the serve points, instead of the serve errors, thus producing an increase in the serve efficacy. In addition, when the serve is made from zone five (OR = 0.292), instead of from zone one, there is a decrease in serve efficacy, when descending the serve points, instead of the serve errors. Finally, when the serve was directed towards the long diagonal (OR = 1,710), instead of the average diagonal, it increases the serve efficacy, by increasing the serve point, instead of the serve error.

Conclusion: In volleyball world-class U-21 category, the predictors of serve efficacy are: in-game role of the serve (setter, middle attacker), serve zone (zone 5), type of set (Jump float serve), and serve direction (long cross-court). These results can guide the training process by helping to design specific tasks to improve the serve efficacy.

TABLE 1: Adjusted model for serve efficacy.

Variables	Error %[a]	Continuity %	OR crude	OR adjusted	*p*	Point %	OR crude	OR adjusted	*p*
In-game role of the serve									
Setter	13.4	78.9	1.254 (0.884–1.779)[c]	0.845 (0.585–1.221)[c]	0.371	18.1	2.083 (1.165–3.727)[c]	2.2265 (1.242–4.128)[c]	**0.008**
Middle attacker	12.6	84	1.416 (1.058–1.895)	1.007 (0.708–1.639)	0.729	3.4	0.963 (0.538–1.724)	2.392 (1.103–5.190)	**0.027**
Opposite	24.6	71.4	0.616 (0.453–0.837)	0.607 (0.439–0.841)	**0.003**	3.9	0.574 (0.293–1.127)	0.653 (0.328–1.300)	0.225
Receiver-attacker[b]									

(*Continued*)

TABLE 1: (Continued)

Variables	Error %[a]	Continuity %	OR crude	OR adjusted	*p*	Point %	OR crude	OR adjusted	*p*
Serve zone									
Zone 5	15.5	82.1	1.121 (0.861–1.460)	0.498 (0.335–0.740)	**0.001**	2.5	0.443 (0.243–0.8080)	0.292 (0.127–0.668)	**0.004**
Zone 6	15.9	80.9	1.075 (0.755–1.532)	0.830 (0.567–1.216)	0.339	3.2	0.568 (0.265–1.215)	0.600 (0.270–1.331)	0.209
Zone 1[b]									
Type of serve									
Jump float serve	25.3	66.8	3.218 (2.547–4.067)	3.810 (2.866–5.064)	**0.000**	7.9	0.797 (0.504–1.261)	0.835 (0.487–1.433)	0.513
Jump serve[b]									
Serve direction									
Long cross-court	16.9	76.1	0.873 (0.668–1.141)	0.916 (0.689–1.218)	0.916	7.1	1.769 (1.080–2.896)	1.710 (1.021)	**0.042**
Parallel	16.2	80.2	0.960 (0.724–1.274)	0.884 (0.659–1.186)	0.884	3.6	0.945 (0.520–1.718)	0.990 (0.540–1.814)	0.973
Mid cross-court[b]									

[a]Category of references for the dependent variable.
[b]Category of references for the independent variable.
[c]Numbers in brackets refer to the 95% confidence interval.
Bold values: $p < 0.05$.

Acknowledgements

This study was made possible thanks to the contribution of the University of Extremadura and Group Banco Santander. This study was made possible thanks to the contribution of the Consejería de Economía e Infraestructuras of the Junta de Extremadura (Spain) through the European Regional Development fund.

REFERENCES

García-de-Alcaraz, A., Ortega, E., and Pala, J. M. (2016). Effect of age group on technical–tactical performance profile of the serve in men's volleyball. *Percept. Mot. Skills* 123, 508–525. doi: 10.1177/0031512516660733

Quiroga, M., García-Manso, J., Rodríguez-Ruiz, D., Sarmiento, S., De Saa, Y., and Moreno, M. P. (2010). Relation between in-game role and service characteristics in elite women's volleyball. *J. Strength Cond. Res.* 24, 2316–2321. doi: 10.1519/JSC.0b013e3181e3812e PMID:20703161

Quiroga, M., Rodriguez-Ruiz, D., Sarmiento, S., Muchaga, L., Grigoletto, M., and Garcia-Manso, J. (2012). Characterizations of the main playing variables affecting the service in high-level women's volleyball. *J. Quant. Anal. Sports* 8, 1–11. doi: 10.1515/1559-0410.1348

Silva, M., Lacerda, D., and Joao, V. (2014). Match analysis of discrimination skills according to the setter defence zone position in high level volleyball. *Int. J. Perform. Anal. Sport* 14, 463–472. doi: 10.1080/24748668.2014.11868735

Learning Dynamical Systems Concepts through Movement Analogies

Robert Hristovski[1†], Natàlia Balagué[2†], Pablo Vázquez[2†], Carlota Torrents[3†], Aleksandar Aceski[1†]

[1]Faculty of Physical Education, Ss. Cyril and Methodius University, Sport and Health Skopje, Skopje, Macedonia

[2]National Institute of Physical Education of Cataloina (INEFC), University of Barcelona, Barcelona, Spain

[3]National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain

robert_hristovski@yahoo.com

[†]Complex Systems in Sport Research Group.

Introduction: Fragmented scientific understanding seems to be caused dominantly by existence of emergent levels of substance organization whose key properties cannot be formally, i.e., mathematically, deduced from the laws that govern the behavior of the more microscopic components. Therefore, each level is endowed with specific and novel structures and properties which need a specific language to explain them. These languages, thus, use context-dependent concepts to name and explain the processes under scrutiny. Context dependence is viewed essentially as a major cause of the fragmentation between the vocabularies of different scientific disciplines. That is, while within specific scientific fields and subfields the communication of knowledge is made possible by a common vocabulary, the more distant disciplines are, the more difficult communication becomes. As this language fragmentation is also translated into science education, this inevitably leads to the formation of a fragmented worldview in learners and limits the possibilities of a learning transfer between different scientific subjects. In his UN manifesto "Seven complex lessons in education for the future," Edgar Morin made a plea for an integrated approach in education. In his view, the contemporary education, based on a fragmented structure of topics, limits reasoning and critical thinking in students, contributing little to the development of the integrative competencies and knowledge considered essential in modern society. The main issue, then, becomes how to integrate and reduce the barriers within and between widely different areas as STEM (Science, Technology, Engineering, and Mathematics) and Humanities, which is not achieved by various forms of multidisciplinary and interdisciplinary approaches. We think that the tension arising from the coexistence of context-dependent and unifying tendencies in science can be seen as an opportunity rather than a problem: resolving it may result in explanatory patterns that are characterized by both a coherent explanatory skeleton coming from unifying tendencies and flexibility due to its context-dependent vocabulary (Hristovski et al., in press). We propose that this integration would be possible through teaching common concepts and principles of dynamical systems. Moreover, we claim that physical activities in a form of movement analogies may form the content of such an integrative education through formation of an embodied and experientially grounded understanding (Hristovski et al., 2014). The application of movement analogies for teaching pluricontextual and transdisciplinary concepts is the objective of the proposed teaching methodology, that through the learning platform www.SUMA.edu.mk aims: (1) to help teachers and students to discover and learn the connecting dynamic conceptual patterns common to STEM and Humanities, (2) to promote a synthetic understanding, and (3) to contribute to building a synthetic world view. The proposed embodied and experientially grounded-based understanding can be applied to all education levels, including early ages. It is expected that the development of learning transfer and integrative competencies in students will empower them to face the novel and challenging emergent problems of our society.

REFERENCES

Hristovski, R., Balagué, N., and Vázquez, P. (2014). "Experiential learning of the unifying principles of science through physical activities," in *Systems Theory: Perspectives, Applications and Developments*, ed. M. Francisco (New York: Nova), 37–48.

Hristovski, R., Balagué, N., and Vázquez, P. (in press). "Science as a self-organizing cognitive system. Coherence and flexibility of scientific explanatory patterns," in *Complexity Applications in Language and Communication Sciences*, eds A. Bastardas, A. Massip, and G. Bel (Heidelberg: Springer).

Observational Analysis of the Force Applied in 1vs1, Ball Screen and Shooting Situations in ACB

Margalida Lladonet, **Jorge Serna**, **Verónica Muñoz**

National Institute of Physical Education of Catalonia (INEFC), University of Lleida, Lleida, Spain
margalladonet@hotmail.com

Introduction: Basketball can be categorised as an opposition–cooperation sport (Serna et al., 2015) because although the cooperation relationship is obvious (five players coaching each other), the key point in the game is the efficiency in the opposition relationship which means getting the ring of the rival team (Serna, 2014). In order to achieve this, players with the ability to get advantages for him or for the others are required (Serna et al., 2017). All these issues need force applications, such as acceleration, brake, change of direction, and jump (Gonzalo-Skok et al., 2015). The aim of this research was (a) to create an *ad hoc* tool (OSASB) allowing to analyse the strength applied by the players with the ball in one versus one, pick & roll, and shooting situations; (b) to analyse this kind of situations in ACB Copa del Rey Tournament in 2017.

Methods: Seven games were analysed in ACB Copa del Rey Tournament in 2017, with 2,973 actions in total (1,624 in quarter-finals games, 952 in semi-finals games, and 397 in final game).

Instruments and procedure: Observational *ad hoc* tool was built to analyse actions linked to the force in shootings, one versus one, and ball screen. Following observational methodology (Castellano et al., 2008), we built with the software Lince v. 1.3 (Gabin et al., 2012) a tool called OSASB (Observational System to study Applied Strength in Basketball), with 59 categories organized in seven criteria (Table 1).

Data quality: Quality analysis of data was made in order to determine the intra-observer's reliability. To do so, the observer reviewed one game twice (15 days between each observation). Afterwards, we studied the results obtained through Cohen's Kappa coefficient (Hernández Mendo et al., 2012) with excellent results (values over 0.98). After knowing OSASB was a reliable tool, the other seven games were studied.

Data Analysis: Descriptive statistic was used to analyse frequency distribution, percentage of the sample, and contingency tables to measure the correlation amongst criteria.

Results: Reviewing the game situations, we found the next distribution: one versus one (33.4%), ball screen (30.9%), catch and shoot (18.6%), and shots after the dribble

(17.1%). Besides, our findings showed three different kinds of force demonstration: running force (1,958 actions) and jumping force (1,009 actions). About running force, we can distinguish between acceleration (1,481) and change of direction (477). About accelerations: point guards (PG) were the players with highest rate (54.3%); after them, shooting guards (SG) (18.4%); finally, the other three positions added only the 27.3%. About changes of direction we found 45.9% were made by PG, 21.6% by SG, 12.6% by small forwards (SF), 5.2% by forwards (F), and 14.7% by centers (C).

If we study the jumps, we found different kind of jumps: with two feet (71.1%), monopodial with right (8.2%), and monopodial with left (20.9%). The results showed balance between player positions: 22.2% by PG, 19.7% by SG, 18% by SF, 16.7% by F, and 24.4% by C.

Discussion and conclusion: This research has demonstrated that OSASB is a reliable tool to analyse force expressions in specific situations in basketball. Besides, this analysis shows that basketball skills are continuous force expressions with different features depending on game situation; and therefore, it is very important they are optimized during trainings. OSASB is an interesting tool which can let coaches study the specific strength requirements about their players depending on their individual skills.

TABLE 1: Criteria, categories, and codes in OSASB.

Criteria	Category (code)
Team	Iberostar Tenerife (IB), Baskonia (BK), Real Madrid (RMA), F.C. Barcelona (FCB), Morabanc Andorra (AND), Gran Canaria (GCA), Valencia Basquet (VLC), and Unicaja (UNI)
Player	All the players of each team
Player position	Point guard (PG), shooting guard (SG), small forward (SF), forward (F), and center (C)
Force action	Accelerate (ACC), change of direction (CD), and shooting (FIN)
Offense action	One versus one (1c1), ball screen or pick and roll (BD), shot after dribble (FINB), and Catch and shoot (FINR)
Laterality action	Accelerate to right (ACCD), accelerate to left (ACCE), change of direction to right (CDD), change of direction to left (CDE), jump with two feet (STB), jump with right (STD), and jump with left (STE)
Shooting area	Out of three points line (EXT), inside three points line but out of the paint (INTNOPIN), paint (INTPIN)
Result	Score (OK), miss (KO), foul (FP), turnover (PPIL), pass (PASS), and keep playing (ENJUG)

REFERENCES

Castellano, J., Perea, A., Alday, L., and Hernández Mendo, A. H. (2008). The measuring and observation tool in sports. *Behav. Res. Methods* 40, 898–905. doi: 10.3758/BRM.40.3.898

Gabin, B., Camerino, O., Anguera, M. T., and Castañer, M. (2012). Lince: multiplatform sport analysis software. *Procedia Soc. Behav. Sci.* 46, 4692–4694. doi: 10.1016/j.sbspro.2012.06.320

Gonzalo-Skok, O., Serna, J., Rhea, M. R., and Marín, P. J. (2015). Relationships between functional movement tests and performance tests in young elite male basketball players. *Int. J. Sports Phys. Ther.* 10, 628. PMID: PMC4595916

Hernández Mendo, A., Montoro, J., Reina, Á, and Fernández, J. C. (2012). Desarrollo y optimización de una herramienta observacional para el bloqueo en voleibol. *Revista Iberoamericana de Psicología del Ejercicio y el Deporte* 7, 15–31.

Serna, J. (2014). *Inteligencia motriz e inteligencia emocional en el baloncesto (Tesis doctoral)*. Lleida, España: Universidad de Lleida.

Serna, J., Muñoz, V., Hileno, R., Solsona, E., and Sáez de Ocáriz, U. (2017). Patrones temporales iniciados con bloqueo directo o uno contra uno en baloncesto. *Radiat. Prot. Dosimetry* 26, 81–86.

Serna, J., Muñoz, V., and Lozano, D. (2015). Análisis del entrenamiento del lanzamiento de un jugador de baloncesto. *Revista Internacional de Deportes Colectivos* 22, 14–27.

Neuromuscular Fatigue Reduces the Complexity of Knee Extensor Torque during Fatiguing Sustained Isometric Contractions

Jamie Pethick, **Samantha L. Winter**, **Mark Burnley**

Endurance Research Group, School of Sport and Exercise Sciences, University of Kent, Canterbury, United Kingdom

jamie@jamiesprostringing.co.uk

Introduction: In physiology and sporting performance, variability is often regarded and defined as unwelcome; disturbing the balance of a system and degrading performance (Slifkin and Newell, 1998). Indeed, the absence of variability is thought to be necessary for successful performance. However, it is becoming increasingly apparent that variability plays an integral role in physiological systems, with its presence being constructive and functional (Lipsitz and Goldberger, 1992). Traditionally, variability in physiological outputs is quantified according to its *magnitude*, using the standard deviation or coefficient of variation. Recently, it has become recognised that variability can also be quantified according to its structure, or *complexity*, which characterises its temporal irregularity and long-range (fractal) correlations (Lipsitz and Goldberger, 1992). Measures of complexity provide information on the underlying dynamic state of the system, with the presence of a complex output reflecting the adaptability of the system of origin, and deviations away from this reflecting system dysfunction and a loss of adaptability to external perturbations (Vaillancourt and Newell, 2003). In the case of the neuromuscular system, the complexity of muscle torque provides information about the status of contracting muscle, and its ability to rapidly and accurately adapt motor output in response to task demands (Pethick et al., 2017). It has been demonstrated that neuromuscular fatigue results in a loss of muscle torque complexity during maximal and submaximal intermittent isometric knee extensor contractions (Pethick et al., 2015, 2016). This loss of complexity was manifested as a smoothing of the torque time-series, with the output becoming more predictable and regular. Based on the purported significance of complexity, such decreases are thought to have important implications for task performance, exercise tolerance, and motor control (Vaillancourt and Newell, 2003; Pethick et al., 2016). Fatiguing sustained isometric contractions become more tremulous as fatigue develops (Hunter and Enoka, 2001); which is suggestive of a change in the structure of variability. Whether sustained isometric contractions reduce the complexity of muscle torque output is not yet known; therefore, this study aimed to determine the effect of sustained maximal and submaximal fatiguing isometric contractions on the complexity of knee extensor torque. We hypothesised that maximal and submaximal contractions would result in reduced complexity, measured by decreased approximate entropy (ApEn), indicating increased regularity; and a shift in temporal fractal scaling, measured by increased detrended fluctuation analysis (DFA) α, indicating increasingly Brownian noise.

Methods: Nine healthy participants (seven males, two females; mean ± SD; age 24.6 ± 5.5 years; height 1.74 ± 0.07 m; body mass 68.9 ± 10.3 kg) performed sustained isometric contractions of the knee extensors at 20% maximal voluntary contraction (MVC), to task failure, and at 100% MVC, for 60 s. Torque and surface EMG were sampled continuously. Complexity and fractal scaling were quantified by calculating ApEn, which characterises the regularity of a time-series, and DFA α, which characterises the long-range fractal correlations and noise colour present in a time-series. Global, central, and peripheral fatigues were quantified using MVCs with femoral nerve stimulation performed pre- and post-test. Values were compared by two-way ANOVAs with repeated measures and Bonferroni-adjusted *t*-tests.

Results: Maximal and submaximal sustained isometric contractions resulted in significant increases in global, central, and peripheral fatigue, quantified by decreased MVC torque, decreased voluntary activation, and decreased potentiated doublet torque, respectively (all $P < 0.05$). Muscle torque complexity was reduced by the submaximal contractions (ApEn from 1.02 ± 0.06 to 0.41 ± 0.04; $P < 0.05$; Figure 1), with torque fluctuations becoming more sinusoidal (Figure 2). The fractal scaling of muscle torque was reduced by the maximal contractions (DFA α from 1.41 ± 0.04 to 1.52 ± 0.03; $P < 0.05$; Figure 1), with the torque fluctuations becoming more Brownian (DFA α = 1.50).

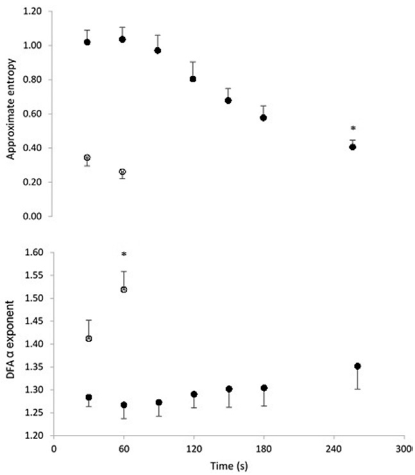


FIGURE 1: Decrease in ApEn (upper panel) and DFA α (lower panel) during intermittent maximal (open circles) and submaximal (closed circles) isometric contractions. * indicates a significant difference from the start of the trial.

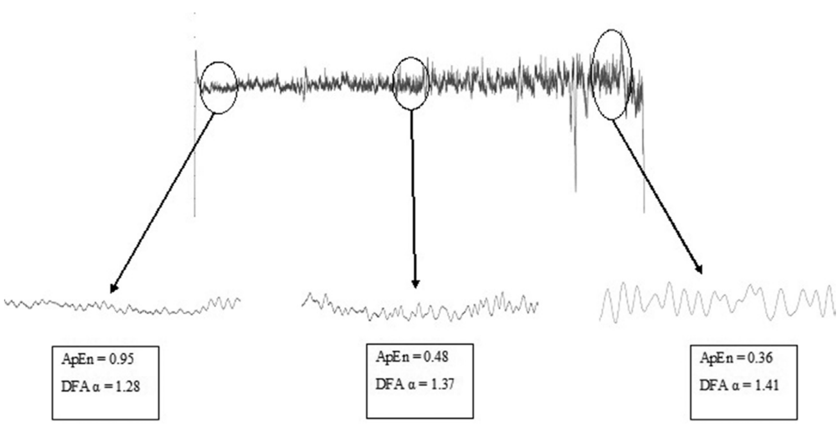


FIGURE 2: Raw torque output from a representative participant in the 20% MVC condition.

Discussion: These results extend previous findings on torque complexity during intermittent contractions to sustained contractions, providing the first evidence that a loss of muscle torque complexity is evident during maximal and submaximal sustained contractions. This provides further confirmation that neuromuscular fatigue compromises the control of muscle torque production and reduces the adaptability of motor output. Whilst the loss of complexity observed during intermittent fatiguing contractions is manifest as a smoothing of the torque time-series (Pethick et al., 2015), the loss of complexity presently observed during the sustained submaximal fatiguing contractions was manifest as apparent sinusoidal behaviour (Figure 2). Both the smoothing of a time-series and more sinusoidal activity are indicative of increased periodicity, regularity, and predictability. This illustrates that the exact nature of the fatigue-induced loss of complexity may be task dependent; depending on the short-term change required to realise task demands. Thus, the differing central and peripheral demands of maintaining torque versus producing it intermittently may lead to differences in the nature of the loss of complexity.

REFERENCES

Hunter, S. K., and Enoka, R. M. (2001). Sex differences in the fatigability of arm muscles depends on absolute force during isometric contractions. *J. Appl. Physiol.* 91, 2686–2694. PMID:11717235

Lipsitz, L. A., and Goldberger, A. L. (1992). Loss of 'complexity' and aging: potential applications of fractals and chaos theory to senescence. *J. Am. Med. Assoc.* 267, 1806–1809. doi: 10.1001/jama.267.13.1806

Pethick, J., Winter, S. L., and Burnley, M. (2015). Fatigue reduces the complexity of knee extensor torque fluctuations during maximal and submaximal intermittent isometric contractions in man. *J. Physiol.* 593, 2085–2096. doi: 10.1113/jphysiol.2015.284380

Pethick, J., Winter, S. L., and Burnley, M. (2016). Fatigue-induced loss of knee extensor torque complexity during isometric muscle contractions occurs exclusively above the critical torque in man. *Am. J. Physiol.* 310, R1144–R1153.

Pethick, J., Winter, S. L., and Burnley, M. (2017). Caffeine ingestion attenuates fatigue-induced loss of muscle torque complexity *Med Sci Sports Exerc*. doi: 10.1249/MSS.0000000000001441.

Slifkin, A. B., and Newell, K. M. (1998). Is variability in human performance a reflection of system noise? *Curr. Dir. Psychol. Sci.* 7, 170–177. doi: 10.1111/1467-8721.ep10836906

Vaillancourt, D. E., and Newell, K. M. (2003). Ageing and the time and frequency structure of force output variability. *J. Appl. Physiol.* 94, 903–912. doi: 10.1152/japplphysiol.00166.2002

Predicting Key-Goal Scoring in Football, Based on Performance Indicators and Contextual Factors

José Maria Pratas[1], Anna Volossovitch,[1] Ana Isabel Carita[2]

[1]CIPER, Faculdade de Motricidade Humana, SpertLab, Universidade de Lisboa, Lisbon, Portugal
[2]CIPER, Faculdade de Motricidade Humana, BIOLAD, Universidade de Lisboa, Lisbon, Portugal
jmpratas@fmh.ulisboa.pt

Introduction: The time/score relationship is a situational factor, which may influence consequent performance and thus should be considered as determinant information for identifying the critical incidents/moments of the game. This work focuses on the goal which decides the result of the game defined as *"key-goal."* The anticipation of temporal localization of the key-goal associated with its nature seems to be useful for a timely change in team tactics. Thus, the aim of this study was to estimate the predictive model of time of key-goal scoring as a function of contextual variables in high-level football games.

Methods: The sample consisted of 306 games played in the Portuguese Premier League in the 2015/2016 season. The cumulative incidence function was used to estimate the probability of each type of key-goal scored during the game. Game outcome was defined as win or draw, while the lost games were not considered. The influence of covariates game venue, accumulated goal and number of scoreline variations on cause-specific hazards for scoring a key-goal was explored using survival analysis with a competing risk model.

Results: The percentage of key-goal scored in each 15-min interval by home and away teams, as well as the game outcome, is presented in Figure 1. The estimated cumulative incidence function (describe the proportion of the total number of games in which a key-goal was scored at time *t*) presented in Figure 2 shows an increase in cumulative key-goal scoring rates over time, with a higher probability of the winning key-goal being scored in all moments of the game, as compared with a drawing key-goal. In order to analyze the effect of covariates for each transition of state a cause-specific hazard ratio (HR) has been estimated and the results support the notion that key-goal scoring is influenced by game venue and the accumulated goal difference (see Table 1).

Discussion and conclusions: This study examined the key-goal scoring characteristics in games played in the Portuguese Premier League. It seems that in the first and final periods, the key-goals of the game occur most frequently and these results pointed out the influence on the final score (i.e., to win the game or avoid the defeat) of an early goal or a goal being scored in the final minutes. According to sources in the literature, the causes for more goals being scored in the final minutes could be attributed to several factors (e.g., mental, physical, or strategic), however, for early goals (goals scored during the first 15 min) the factors related to their occurrences, they are not yet clear. In his autobiography, coach Alex Ferguson (2013) highlighted the last 15 min of a game as being a critical moment for taking risks, making this a decisive period of the game. Home teams presented a probability of scoring the winning key-goal was 32% and the drawing key-goal was 65% higher than that of away teams. These findings are in agreement with those of several studies of home advantage in football (Pollard and Gómez, 2014), for teams scoring a goal in the final minutes and winning a game (Van Ours and Van Tuijl, 2011), teams scoring the first goal of game and those winning the game after scoring the first goal (Pratas et al., 2016). As might be expected, the results also highlighted the effect of accumulated goal difference on key-goal scoring. A positive relationship between a positive accumulated goal difference and game outcome would be expected; however, our findings showed that a positive

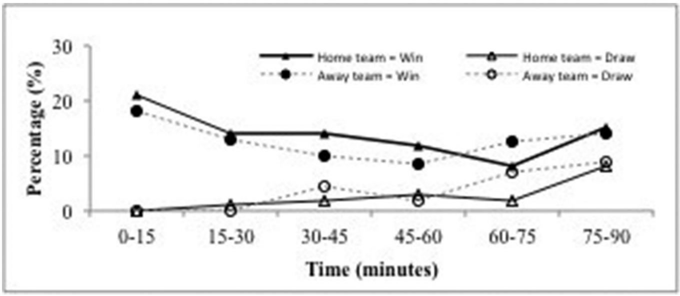


FIGURE 1: Percentage of key-goals scored by home and away teams and the respective game outcome in each of the six 15-min intervals of the games played in season 2015–2016.

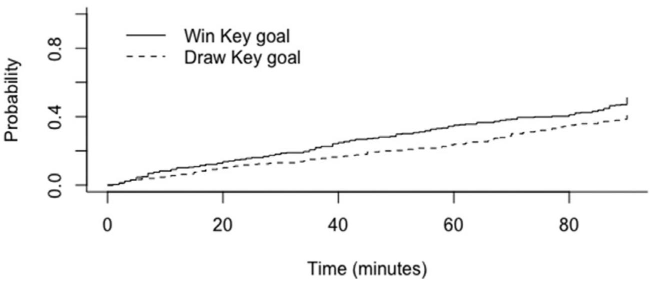


FIGURE 2: Cumulative incidence curves for key goals scoring and the associated game outcome.

accumulated goal difference had a negative effect on winning key-goals. Perhaps one of the reasons for this derives from the imprecise categorization of the goal difference variable, which included only two classes (positive difference and negative difference). Further research should consider more detailed categorization for this variable to improve the analysis of its effect on the key-goal scoring. This study adopts a novel approach, not only focusing on the outcome itself, but also analysing the time which elapses to the occurrence of a crucial event which led to this outcome. Further research should consider including time-varying covariates (explanatory variables whose values change over time), in analysis.

TABLE 1: Competing risks model: effect of covariates on each cause of key-goal scored.

	State 0 to state 1			**State 0 to state 2**		
	Game ended with victory			**Game ended tied**		
	HR	**0.95 CI**	***P*-value**	**HR**	**0.95 CI**	***P*-value**
Game venue						
Away	1			1		
Home	1.32	0.92–1.52	0.048*	1.65	1.41–1.93	<0.001**
Accumulated goal difference						
Negative or null	1			1		
Positive	0.39	0.51–1.06	<0.001**	2.43	1.64–3.58	<0.001**
Scoreline						
One	1			1		
Two or more	0.97	0.80–1.03	0.151	1.01	0.89–1.15	0.824

Statistically significant: $^{**}P < 0.001$, $^{*}P < 0.05$.
HR, hazard ratio; CI, confidence interval.

REFERENCES

Ferguson, A. (2013). *Alex Ferguson: My Autobiography*. London: Hodder and Stoughton.

Pollard, R., and Gómez, M. A. (2014). Comparison of home advantage in men's and women's football leagues in Europe. *Eur. J. Sport Sci.* 14(Suppl. 1), S77–S83. doi: 10.1080/17461391.2011.651490 PMID:24444247

Pratas, J. M., Volossovitch, A., and Carita, A. I. (2016). The effect of performance indicators on the time the first goal is scored in football games. *Int. J. Perform. Anal. Sport* 16, 347–354.

Van Ours, J. C., and Van Tuijl, M. A. (2011). Country-specific goal scoring in the "dying seconds". *Int. J. Sport Finance* 6, 138–154.

Effects of High Intra-Workout Variability during Strength Training

R. Sabido, J. L. Hernández-Davó, A. Verdu, F. J. Moreno

Sport Research Centre, Miguel Hernández University, Elche, Spain
rsabido@umh.es

Introduction: Variability in practice is a widespread topic in motor learning. One of the characteristics of variability practice is to constantly require the CNS to adapt according to task constraints. This idea of variability in strength training can be observed in undulating periodization, through modifications volume and intensity each day during the week. These frequent changes in stimuli (different aim in each session) are advantageous to stress the nervous system and to increase strength (Fleck, 2011). To the best of our knowledge, only one study has analyzed the influence of intra-workout variability (Farris and Luebbers, 2013). Farris and Luebbers did not find differences between intra-workout undulating periodization program and a daily undulating periodization program (DUP) on strength improvement. However, the intensity used in that study was lower than the typical intensity in undulating periodization.

Objective: The aim was to compare the effects of a daily periodization (DP) with an intra-workout variability periodization (IVP) on maximal dynamic strength and jumping ability.

Methods: Twenty-eight participants took part in the study (23.9 ± 3.5 years, 1.73 ± 0.08 m, and 70.4 ± 10.1 kg). The inclusion criteria for participation were to exhibit more than 1.5 in the ratio One-Repetition Maximum (1RM) test in squat/body mass. Participants were randomly distributed into two groups (DP and IVP) according to relative strength (MR/body mass). During 6 weeks each group performed two sessions per week of squat training. DP training group carried out an explosive strength session (6 × 8 jump squat at 30% 1RM), a hypertrophy session (6 × 8 squat at 75% 1RM), and a maximal strength session (6 × 4 squat at 85% 1RM). In the other hand, IVP group included the three kinds of exercises (explosive strength, hypertrophy, and maximal strength) within each session (i.e., 6 sets of 10 repetitions: 4 repetitions at 30% 1RM, 4 repetitions at 75% 1RM, and 2 repetitions at 90% 1RM). Pre and post values of 1RM, squat jump (SJ), and countermovement jump (CMJ) were measured. A two-way ANOVA (group × time) was calculated and statistical significance was set at $p < 0.05$. Cohen's d effect sizes (ES) were also calculated and interpreted as <0.25 = trivial; 0.25–0.50 = small; 0.50–1.0 = moderate; and >1.0 = large (Rhea, 2004).

Results: Changes in 1RM squat are shown in Figure 1. Both DP group (+25%, ES = 1.31) and IVP group (+25%, ES = 1.70) showed significant increases after training. Significant increases were found in both SJ (DP = +10%, ES = 0.87; IVP = +8%, ES = 0.87) and CMJ (DP = +9%, ES = 0.86; IVP = +9%, ES = 1.15) after the training intervention (Figure 2).

Conclusion: Based on the results of the study, both DP and IVP periodization models are an effective way to improve performance in maximal dynamic strength (1RM squat) and lower-limb power (i.e., jumping ability). Nevertheless, the magnitude of these improvements showed greater effect size for the IVP group in the 1RM squat and CMJ performance. Thus, the addition of variability into resistance training sessions seems to be a higher neuromuscular stimulus leading to greater improvements in variables related to strength training.

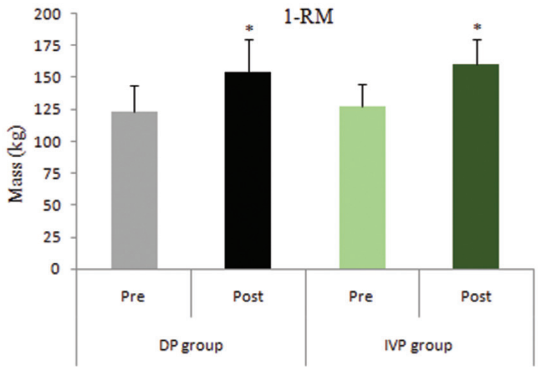


FIGURE 1: Changes in maximal dynamic strength for DP and IVP group after training.*, significantly greater than pre-test.

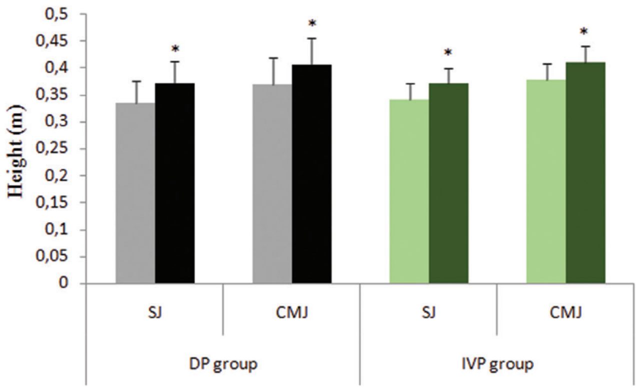


FIGURE 2: Changes in jumping ability for both DP and IVP group after training. * = significantly greater than pre-test.

REFERENCES

Farris, G., and Luebbers, P. E. (2013). A comparison of two undulating periodization programs: daily vs. intra-workout. *Int. J. Exerc. Sci.* 11, 9.

Fleck, S. J. (2011). Non-linear periodization for general fitness & athletes. *J. Hum. Kinet.* 29, 41–45. doi: 10.2478/v10078-011-0057-2 PMID:23486658

Rhea, M.R. (2004). Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J. Strength Cond*. Res.18(4):918–20. doi: 10.1519/14403.1

Methodological Identification of the Training-Competition Relationship in Football: Finishing Situations in a Team of Second Division B

H. Sanfiz

Physical Activity and Sport Sciences, UEFA A Football Coach, Universidade da Coruña, La Coruña, Spain
kykesanfiz@gmail.com

Introduction: Football is a complex phenomenon (Lago, 2000; Martin Acero and Lago, 2005). The experiences, characteristics, and expectations of both coach and players have their influence in the interpretation of reality as their unique configuration (Castellano, 2000; Araújo et al., 2012; Sampaio et al., 2017). The general aim of this study is to identify and analyze, in a Spanish Second B division team, the relationships between behaviors in finishing situations during competition, the interpretation of them by both coach and players and, finally, the previous intention of the coach as the agent of change of the training-competition process in football. We have registered that kind of situations during 24 matches through an *ad hoc* observation instrument. At the same time, we have interviewed every single player and the coach during the 2016–2017 season. We concluded that the analysis of these observations and the methodological relation between finishing situations, interpretations, and the previous intention have allowed for an improvement in the process of reflection and in the decision-making by both coach and players. All of this has allowed the continuous optimization of their intervention in the training-competition process.

Methods: A descriptive methodology was chosen for this paper. Using it, some relationships and discussions of the results were done. For the development of this work, 115 game situations where the team was able to finish the opposing team goal were analyzed. All of them during the 2016–2017 season in Second B division matches. The previously mentioned *ad hoc* instrument is formed by the following categories: (1) Opposing team's level; (2) Location of the match; (3) Partial result; (4) Way of starting; (5) Area of starting; (6) Number of passes in the interval; (7) Duration; (8) Number of passes and variations of lanes; and (9) End of ball possession. The reliability between the records of two observations has been evaluated by intra-observer concordance using the Kappa coefficient, obtaining for all categories an almost perfect reliability, between 0.81 and 1. What is more, a structured interview was done to each one of the 24 players of the squad and the coach, trying to know how each of them understands that the team is able to create and take advantage of the finishing situations. For that reason, every subject has answered nine questions related with the previously mentioned categories. At the same time, the whole of the squad was divided in the following groups: (a) Players with bigger experience; (b) Players with less experience; (c) Players who played more minutes; (d) Players who played less minutes; and (f) Coach. Finally, the coach was also interviewed in order to know his previous intention of the training process in relation to the creation and the use of the finishing situations. He answered eight questions related with the previously mentioned categories with the exception of the category (9).

Results: It has been observed how the team uses MDC+MOC spaces as a Starting zone, and there is agreement with the interpretation of groups of Players with more minutes (83.3%), more experience (66.66%), and the coach's perception. Something similar happens with the Number of passes in the interval (<3 per sequence), where we have observed a high concordance between reality (90.53%), with the interpretation of the coach (100%) and groups of players with more experience (91.63%), more minutes (74.97%), less experience (58.31%), and less minutes (58.31%). In relation to the Start mode "Interception + pass out of recovery zone" there is agreement between observed reality (24.34%), coach perception (100%), and groups of players with more minutes (50%), less minutes (33.32%), more experience (50%), and less experience (50%). There is also a concordance between the Previous intention and the reality observed in the Area of starting and Way of starting categories. The team has a greater tendency to initiate its offensive sequences in the MDC zone (12.17%) by means of Intercept + pass outside the sub-zone (24.34%), behaviors intended by the training process.

Discussion and conclusion: The evaluation of performance indicators plays an important role in the sports sciences. In this way, understanding how players and soccer teams behave and interact during the game can be a solid criterion for modeling the training process and increasing the probabilities of winning in competition (Sampaio et al., 2017). With this investigation it is possible to conclude that the use of instruments and investigation analysis of the methodological relation studied (real finalizations/ interpretations/previous intention) increases the broadness and the deepness of the knowledge of the football players and the coach in relation to the training-competition process, making easier a more efficient decision making by the staff in order to increase the performance in competition.

REFERENCES

Araújo, D., Duarte, R., Correia, V., and Davids, K. (2012). Sports teams as superorganisms. *Sports Med.* 42, 633–642. doi: 10.1007/BF03262285

Castellano, J. (2000). *Observación y análisis de la acción de juego en el fútbol.* Tesis doctoral, Universidad del País Vasco, Vitoria-Gasteiz.

Lago, C. (2000). *La acción motriz en los deportes de equipo de espacio común y participación simultánea*. Tesis de doctorado. La Coruña: Universidade da Coruña

Martin Acero, R., and Lago, C. (2005). *Deportes de equipo: comprender la complejidad para elevar el rendimiento*. Barcelona: INDE.

Sampaio, J., Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., and Jiménez, S. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS ONE* 12:e0171156. doi: 10.1371/journal.pone.0171156 PMID:28141823

Sports Teams as Complex Adaptive Systems: A Systematic Literature Review

Pedro J. Ramos-Villagrasa[1], Pedro Marques-Quinteiro[2], José Navarro[3], Ramón Rico[4]

[1]*Universidad de Zaragoza, Zaragoza, Spain*
[2]*ISPA – Instituto Universitário, Lisboa, Portugal*
[3]*Universidad de Barcelona, Barcelona, Spain*
[4]*University of Western Australia, Crawley, Australia*
ramospedro@uniovi.es

Introduction: Seventeen years ago, Arrow et al. (2000) portrayed teams as complex adaptive systems (CAS). Thus, the study of groups, including sports teams, should consider that these are entities characterized by nonlinear relationships, chaotic dynamics, fractal structure, catastrophic changes, and emergence. Although this idea was well received and widely cited, the amount of empirical research approaching teams as CAS remains scarce (Ramos-Villagrasa et al., 2012). This research is a systematic review aimed to demonstrate the actual contribution of CAS to sports teams by: (1) systematizing current knowledge and (2) showing the value of using CAS in empirical sport research.

Methods: We generated the search criteria pairing the word "team" with keywords related with CAS (i.e., dynamics, non-linear dynamics, chaos, chaotic, complex adaptive systems, fuzzy sets, phase space, phase transition, perturbation, stability, and social network analysis). These keywords were introduced on EBSCO Host and Web of Science databases, searching for papers using quantitative methods published between 2000 and 2016. After that, we conducted three consecutive filtering rounds: (1) gather the articles founded the databases; (2) read the abstracts to determine if it fits to our objectives and to remove duplications; and (3) read the remaining articles, considering only those related with sports teams. Applying this procedure, 32 manuscripts were systematically reviewed. The list of references can be obtained from the first author, by e-mail.

Results: Results in Figure 1 show that research has focused on coordination, movement, and performance. Regarding coordination, the main finding is that there are several kinds of coordination episodes in a match, e.g., between team members, between attacker–defender dyads, and between rival teams. The article by Bourbousson et al. (2010) is a good example of these. Regarding movement, studies like those by Travassos et al. (2011), Camerino et al. (2012), and Esteves et al. (2015) show that sports teams have a pace with regularities than can be described and predicted using CAS. Thus, Travassos et al. (2011) analyzed interactions in waterpolo teams to find how interaction peaks signal which player is the key decision maker during the game. In a similar way, Camerino et al. (2012) used T-patterns approach to describe players' movements

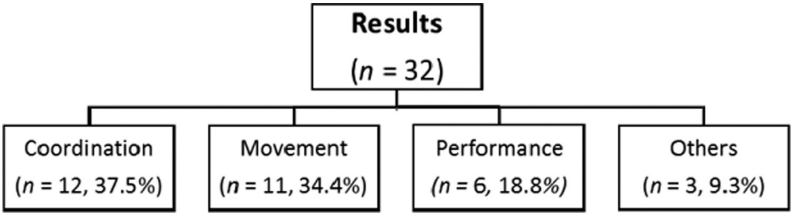


FIGURE 1: Results of the systematic review.

and to determinate which interactions increased the odds of scoring. Finally, research by Esteves et al. (2015) with soccer players has shown that interpersonal distance between attackers and defenders has an impact on goal chances. Finally, we found in the literature signals of performance being linked to "healthy variability," i.e., an optimum state of variability in a complex system that predicts optimal performance. For example, Ramos-Villagrasa et al. (2012) examined the performance dynamics of basketball teams over 12 seasons. They found that all teams exhibit a chaotic pattern in their performance over time, and that the top performing teams displayed a low-dimensional chaotic pattern. Another study with rugby teams, by Correia et al. (2011) found that the effectiveness of attacking teams is predicted by the variability of their movements and by entropy levels in players' movements. These studies support the idea of healthy variability at different levels of analysis (i.e., performance at team level and movements at members level).

Discussion and conclusion: Our systematic review has shown that empirical research on sports using CAS is producing fruitful outcomes in three topics: coordination, movement, and performance. Nevertheless, from our point of view, this review also suggests that more effort is needed to convince other researchers to embrace CAS. To reach this goal, two conditions are necessary: (1) discussing the practical implications of the results of their research and how these outcomes cannot be obtained using the traditional linear approaches (e.g., general linear models) and (2) to develop easy to follow guidelines regarding how to perform empirical research on sports teams as CAS, which is *complex* in the theoretical and analytical approach but not *hard* to learn and closer to *reality*. It is our hope that sports researchers continue guiding the maturation of teams as CAS in the following years.

Acknowledgements
The authors would like to acknowledge the Spanish National Plan for R&D, Ministry of Economy and Competitiveness (PSI2012-31135, RR, Principal Investigator, and PSI2013-44854-R project, PR-V and JN, Investigators) for support that, in part, assisted the composition of this article. William James Center for Research, ISPA – Instituto Universitário is financed by FCT (Ref. UID/PSI/04810/2013).

REFERENCES

Arrow, H., McGrath, J. E., and Berdahl, J. L. (2000). *Small Groups as Complex Systems: Formation, Coordination, Development, and Adaptation*. California, USA: SAGE.

Bourbousson, J., Sève, C., and McGarry, T. (2010). Space–time coordination dynamics in basketball: part 1. Intra-and inter-couplings among player dyads. *J. Sports Sci.* 28, 339–347. doi: 10.1080/02640410903503632

Camerino, O., Chaverri, J., Anguera, M. T., and Jonsson, G. K. (2012). Dynamics of the game in soccer: detection of T-patterns. *Eur. J. Sport Sci.* 12, 216–224. doi: 10.1080/17461391.2011.566362

Correia, V., Araújo, D., Davids, K., Fernandes, O., and Fonseca, S. (2011). Territorial gain dynamics regulates success in attacking sub-phases of team sports. *Psychol. Sport Exerc.* 12, 662–669. doi: 10.1016/j.psychsport.2011.06.001

Esteves, P. T., Silva, P., Vilar, L., Travassos, B., Duarte, R., Arede, J., et al. (2015). Space occupation near the basket shapes collective behaviours in youth basketball. *J. Sports Sci.* 34, 1557–1563. doi: 10.1080/02640414.2015.1122825

Ramos-Villagrasa, P. J., Navarro, J., and García-Izquierdo, A. L. (2012). Chaotic dynamics and team effectiveness: evidence from professional basketball. *Eur. J. Work Organ. Psychol.* 21, 778–802. doi: 10.1080/1359432X.2012.669525

Travassos, B., Araújo, D., Vilar, L., and Mcgarry, T. (2011). Interpersonal coordination and ball dynamics in futsal (indoor football). *Hum. Mov. Sci.* 30, 1245–1259. doi: 10.1016/j.humov.2011.04.003 PMID:21683464

Dynamic Sequences in Possession of One La Liga's Team along Two Seasons

Marc Vives[1], Jordi Martín[1], Raúl Hileno[2], Carlota Torrents[2], Ángel Ric[2]

[1]*National Institute of Physical Education of Catalonia (INEFC), Universitat de Barcelona, Barcelona, Spain*
[2]*National Institute of Physical Education of Catalonia (INEFC), Universitat de Lleida, Lleida, Spain*
marcvives@fcf.cat

Introduction: Dynamical approaches enable the analysis of football game paying attention to qualitative patterns of actions and interactions. Performance analysts have used statistical physics to study the connection of the different dimensional structures that make up the player with network metric studies. Besides, network analysis has been widely used to shape tactical behaviour in football through the notation of interaction opportunities between player's positions and the progression of the ball (Grund, 2012). The objective of this study is to analyse the different patterns in possession comparing passing sequences depending on the final event. Thus, in order to make easier the capture of the dynamics and facilitate the context interpretation of such data, the mathematical organization of the interactions has been presented through network analysis (Passos et al., 2011).

Methods: Frequencies and relative probabilities of passing or receiving the ball in 13 pitch zones have been analysed in one *La Liga*'s team during the 2009–2010 and 2010–2011 seasons. All the attacking sequences in possession were analysed from a sample of 32 matches, collecting a total of 1,697 passes. The notation of the zone, where each pass was realized, has been collected using MATCH VISION STUDIO 1.0. software. This notation allows the creation of a passing network, composed of pitch zones (nodes) connected by passes (edges). A total of 16 nodes were established: possession recovery (REC), eight gestation zones (GZ1, GZ2, GZ3, GZ4, GZ5, GZ6, GZ7, and GZ8), five ending zones (EZ1, EZ2, EZ3, EZ4, and EZ5), shot (SH), and loss of ball possession (LBP). Chi-square test was used to observe significant differences, and intraobserver reliability was verified by a study of generalizations in the GT v. 2.0.

Results: Results show significant differences between passes behaviour of the team when the possession ends with a shot, or the loss of the ball ($X^2 = 315.51$ df = 194 $p < 0.001$). Data collected is summarized in Figures 1 and 2, where the colour transparency means probabilities, and edges weight is associated with frequencies.

Discussion: Team shows a vertical pattern when playing out from the back, being more probable to recover ball possession in gestation zones GZ8, GZ7, GZ6, and GZ5 (Gonçalves et al., 2017). The attacking structure progresses playing middle with more dynamic associations, increasing the probability to pass the ball at ending zones. Referring to the behaviour at these zones, probabilities and frequencies to shot enlarge if wingers do not carry the full weight of the attack in a single corridor.

Conclusion: The use of this kind of analysis allows the recognition of the most likely channels chosen by a team to reach successfully ending zones and finish possession through a shoot. Future research opens the door to the possibility of analysing the pass dynamics depending on the pitch localization where the team recovers possession.

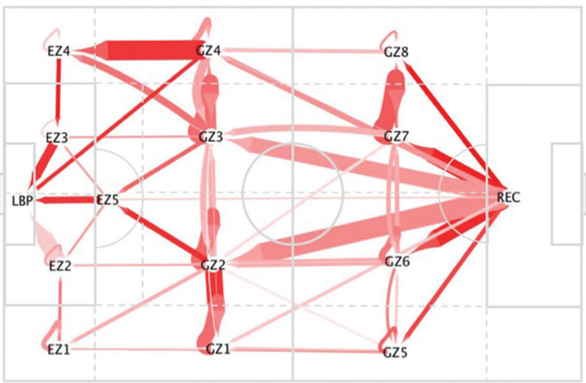


FIGURE 1: Passing frequencies and probabilities when possession finishes with shot.

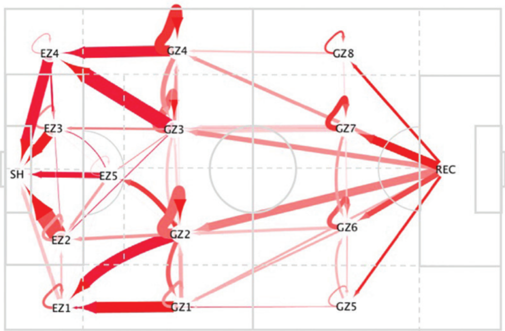


FIGURE 2: Passing frequencies and probabilities when possession finishes with loss of ball possession.

REFERENCES

Gonçalves, B., Coutinho, D., Santos, S., Lago-Penas, C., Jiménez, S., and Sampaio, J. (2017). Exploring team passing networks and player movement dynamics in youth association football. *PLoS ONE* 12:e0171156. doi: 10.1371/journal.pone.0171156 PMID:28141823

Grund, T. U. (2012). Network structure and team performance: the case of English Premier League soccer teams. *Soc. Networks* 34, 682–690. doi: 10.1016/j.socnet.2012.08.004

Passos, P., Davids, K., Araujo, D., Paz, N., Miguens, J., and Mendes, J. (2011). Networks as a novel tool for studying team ball sports as complex social systems. *J. Sci. Med. Sport* 14, 170–176. doi: 10.1016/j.jsams.2010.10.459 PMID:21145787

Advantages of publishing in Frontiers

OPEN ACCESS
Articles are free to read, for greatest visibility

COLLABORATIVE PEER-REVIEW
Designed to be rigorous – yet also collaborative, fair and constructive

FAST PUBLICATION
Average 85 days from submission to publication (across all journals)

COPYRIGHT TO AUTHORS
No limit to article distribution and re-use

TRANSPARENT
Editors and reviewers acknowledged by name on published articles

SUPPORT
By our Swiss-based editorial team

IMPACT METRICS
Advanced metrics track your article's impact

GLOBAL SPREAD
5'100'000+ monthly article views and downloads

LOOP RESEARCH NETWORK
Our network increases readership for your article

Frontiers
EPFL Innovation Park, Building I • 1015 Lausanne • Switzerland
Tel +41 21 510 17 00 • Fax +41 21 510 17 01 • info@frontiersin.org
www.frontiersin.org

Find us on