International Journal of Sports Science 2016, 6(1A): 1-7
DOI: 10.5923/s.sports.201601.01

Network of Interpersonal Interactions in Roller Hockey

Vasco Vaz[1], Gonçalo Dias[1,*], José Gama[1], Micael Couceiro[2,3], João Vantente-dos-Santos[1,4], João Rafael[1], José Alberto Areces Gayo[5]

[1]Faculty of Sport Science and Physical Education, University of Coimbra, Coimbra, Portugal
[2]Artificial Perception of Intelligent Systems and Robotics (AP4ISR), Institute of Systems and Robotics (ISR), University of Coimbra, Coimbra, Portugal
[3]Ingeniarius, Ltd., Portugal
[4]Lusófona University of Humanities and Technologies, Faculty of Physical Education and Sport, Lisbon, Portugal
[5]Faculty of Sport Sciences and Physical Education, University of Galiza, Galiza, Spain

Abstract The aim of this study was to identify the number of intra-team interactions and to examine which athletes have more interactions with their peers through the use of pass. We analyzed the preferential connectivity levels of specific players, highlighting their interactions and identifying those who had the greatest influence on ball movement. The sample consisted of 8 Portuguese, highly trained male roller hockey players (aged between 14.5 and 16.5 years), selected to participate in the 2007 and 2008 editions of the U-17 European League. Results showed that player 8 ($g_8 = 0.6686$) and player 6 ($g_6 = 0.6569$) presented the highest global rank of the team in terms of promoted interactions.Generally, these results permitted the identification of the centroid player and his role in a team activity. It was concluded that roller hockey could be described as an open system able to create clusters of connectivity between players. The herein presented findings may help coaches and sport scientists to better understand how the collective behaviour is orchestrated.

Keywords Interpersonal coordination, Interaction, Performance, Young athletes

1. Introduction

Networks of individual and collective decisions can be used to quantify the performance of individual players in a team activity [6, 10, 15, 27]. As in other team sports (e.g., basketball, handball or soccer), the performance structure of roller hockey is complex [13] and, therefore, depends on player's decisions that occur in contexts and environments with high variability and instability [12, 14, 27].

Notational analysis of highly trained male adolescent roller hockey players indicated an average of 130 ball possessions per 50-min game [15]. The majority of ball possessions derived from interpersonal interactions between players [15], suggesting this trait as an important component of hockey performance.

Network analysis was recently used to map actions and interactions of players during a game of water polo [19]. The concept has its origins in Social Sciences and Biology, among other areas of research [1, 2, 16, 16]. Applied to sport, enables the possibility to investigate not only the number of interactions that occur in a given period of space and time, but also, to understand team's coordination patterns in the course of individual and collective dynamics.

* Corresponding author:
goncalodias@fcdef.uc.pt (Gonçalo Dias)
Published online at http://journal.sapub.org/sports

Research dealing with these theoretical assumptions in the context of sport is rather limited [19, 24, 28] and does not systematically consider the broader scopes that go beyond the usual prospective or retrospective actions of success or failure [23]. Behavioral information that can optimize players and teams effectiveness are of prime interest to many of those involved in the sport [4].

Therefore, the purpose of this study was to identify the number of intra-team interactions and to examine which athletes have more interactions with their peers through the use of pass. A further aim was to examine the influence of interpersonal actions on competitive performance and the final result of the game. Weanalyzed the preferential connectivity levels of specific players, highlighting their interactions and identifying those who had the greatest influence on ball movement [10].

It was hypothesized that the centroid player maintains the connectivity of the whole team. It was also hypothesized that roller hockey could be described as an open system able to create nets or clusters of connectivity between players.

2. Material and Methods

2.1. Participants

The sample comprised 8 outfield male competitive roller hockey players aged 14.5-16.5 years. These players represented the Portuguese national team, which participated in the 2007 and 2008 editions of the U-17 European Championship. Players were classified as defenders (*n* = 4; players 3, 4, 6 and 8) and forwards (*n* = 4; 2, 5, 7 and 9). All players participated in regular training sessions at their clubs (4–6 sessions per week, ~360–510 min per week) and typically played 1 or 2 games per week over a 10-month period (mid-September to June). All participants had been engaged in formal training and competition for at least 5 years. The national team preparation for the European Championship occurred 4 weeks before the competition, and the training volume increased to 15 sessions per week (~1050 minutes) in the first two weeks, and then decreased to 10 sessions per week (~825 minutes) in the last two weeks.

2.2. Measures and Procedures

Data collection included five games of the European Championship and 1039 collective offensive actions. Two digital cameras Sony Mz 25 DCR70 were used and images were processed at 25 Hz. Register grates that supported the coding of images to stock frequencies and their times were prepared in accordance with the work presented by Mendo and Argilaga [15]. After registration in the game observation grates, we proceeded to the registration of the data in the Excel spreadsheet, which was design for this purpose. The categorization of variables aimed an overall assessment of all the actions, verifying the analytic contribution of each player in their actions.

The data was represented by a nonsymmetrical weighted adjacency matrix A_w, in which the upper-triangle corresponds to the number of pass actions made, while the lower-triangle corresponds to the number of pass actions received (the diagonal that subdivides the matrix is ignored). As an example, the number of pass actions player i does with player j is represented by w_{ij}, which may, or may not, be the same as the number of pass actions player j did with player i, $w_{ij} \neq w_{ji} w_{ij} \neq w_{ji}$.

Based on this matrix, we adopted a schematic representation of a roller hockey (see results section, Figure 2) to identify, and later definition of variables involved in the typology of game. The schematic representation of a roller hockey was based on the one already used by Mendo and Argilaga [15], which has split up the rink in eighteen areas with six sectors and three side lanes.

During the offensive process roller hockey player's act in depth and breadth using quick actions of progression with the ball or pass [15]. Nevertheless, pass is the technical element that best distinguishes the interaction between players [4, 10, 19, 23].

The data obtained were inserted on an Excel Template, version Node XL program 1.0.1.164. Through this application, it was possible to get connectivity matrices and establish the mapping of interactions that took place between players in the context of the match. To this end, were created two arrays of double-entry, which aimed to present the interactions between players that resulted from passes established in different parts of the schematic representation of a roller hockey.

All procedures used in this study were approved by the Ethics Committee of the Faculty of Sport Sciences and Physical Education, University of Coimbra, following the guidelines of the American Psychological Association for research involving human participants. All participants provided informed consent to take part in this research.

Finally, to better understand the net of interactions, which emerge from player of the same team, we used the relative frequency probability method, by the following equation [20]:

$$p(w_{ij}) = \frac{w_{ij}}{\sum_{i \neq j} w_{ij}}, \quad (1)$$

Where in $p(w_{ij})$ is the probability of a given interaction w_{ij} to occur between player i and j. It needs to be noted that probability of an interaction occurs, as it is defined, results on a relative frequency of occurrence. Thus, the probability is a number such that: $0 \leq p(w_{ij}) \leq 1$.

Besides the probability of interaction between pairs of players, we computed an intra-player network concept (network property of a node), denoted as the *centroid players*). To computed is network concept, one can create a new relative weighted adjacency matrix $A_r = [r_{ij}] \in \mathbb{R}^{n \times n}$, defined as:

$$r_{ij} = \begin{cases} \frac{w_{ij}}{\max_{i \neq j} A_w}, & i \neq j \\ w_{ij} & , i = j \end{cases}, \quad (2)$$

Where $0 \leq r_{ij} \leq 1$ for $i \neq j$, with $i, j = 1, \ldots, n$. The denominator $\max_{i \neq j} A_w$ corresponds to the larger connectivity between players, the players that interact the most together. Note that, as the weighted adjacency matrix A_w, A_r is also nonsymmetric.

Afterwards, one needs to compute a widely used concept for distinguishing a vertex of a network (cf. [11]), called the *connectivity* (also known as degree). The connectivity of player i can be defined by:

$$k_i = \sum_{i \neq j} r_{ij}, \quad (3)$$

Such that $k = [k_i] \in \mathbb{R}^{1 \times n}$ is the vector of the connectivity of players. Note that there will be a vector for the pass actions made and another for the pass actions received. In other words, player i may present a high connectivity with the team due to the actions he make, but may not present a high connectivity with the team regarding the pass actions received.

The most cooperative player, or players, can be found by finding the index/indices of the maximum connectivity for the pass actions made and received as:

$$k_{max} = \max_j k_j. \quad (4)$$

Therefore, one can define a relative connectivity, known as *scaled connectivity*, of player i as:

$$s_i = \frac{k_i}{k_{max}}, \quad (5)$$

Such that $s = [s_i] \in \mathbb{R}^{1 \times n}$ is the vector of the relative connectivity of players. Note, once again, that there will be a vector for the pass actions made and another for the pass actions received.

In team sports context, one could interpret the scaled connectivity as a measure of cooperation level of a given player in which high values of s_i (as s_i tends to 1) indicate that the i^{th}player works with most of the other teammates.

However, a player may present a high connectivity with other players but may be unable to produce consensus among his non-direct teammates. In other words, he may interact with several other players directly that does not directly interact with each other. Therefore, the *clustering coefficient* of player i offers a measure of the degree of inter-connectivity in the neighborhood of player$i$, being defined as:

$$c_i = \frac{\sum_{j \neq i} \sum_{l \neq i,j} r_{ij} r_{jl} r_{ki}}{\left(\sum_{j \neq i} r_{ij}\right)^2 - \sum_{j \neq i} \left(r_{ij}\right)^2}, \quad (6)$$

Such that $c = [c_i] \in \mathbb{R}^{1 \times n}$ is the vector of the clustering coefficient of players. Note that there will be a vector for the pass actions made and another for the pass actions received.

The relationship between the clustering coefficient and the connectivity has been used to describe structural (hierarchical) properties of networks [22]. As a team sports modality, a weighting distribution of the cluster coefficient and the connectivity between players should be taken into account. Therefore, a weighting function, denoted as *global rank*, was defined as:

$$g_i = \rho_s s_i + \rho_c c_i \quad (7)$$

Where $\rho_s + \rho_c = 1$, such that $g = [g_i] \in \mathbb{R}^{1 \times n}$ is the vector of the global rank of researchers. Note that there will be a vector for the pass actions made and another for the pass actions received. Also note that the scaled connectivity s_i was chosen over the unscaled one k_i since it lies between 0 and 1 as the clustering coefficient, thus resulting in $0 \leq g_i \leq 1$.

Taking into account that the main objective of the hockey team, as any other collective sport, is to give priority to the collective performance (the overall interaction between players), one can ponder a balanced consideration of $\rho_s = \rho_c = 0.5$. The top-ranked player (s), the one (s) presenting the higher g_i, will then be denoted as the *centroid players*. Within sports team, the *centroid player*(*s*) could be considered as the player(s) who maintain(s) the connectivity of the whole team.

3. Results

As shown in Table 1, 1039 interactions were noted between youth players of national roller hockey team, regarding the studied game-related statistics. Note that, as previously stated, interactions made and received correspond to passes made and received between pairs of players.

The highest numbers of interactions (n = 62) were noted between players 8 and 6 and between players 6 and 8 (*n* = 61). Accordingly, player 6 was the player with a higher number of interactions (*n* = 205), followed by player 8 (*n* = 206). On the other hand, player 4 was the one with the lower number of interactions received (*n* = 57).

Player 8 was the one with highest intervention index (sum of interactions made and received) with 406 interventions, along with player 6 that showed 399. In contrast, player 4 was the player who got a lower level of intervention (*n* = 112). In addition to Table 1, Figure 1 shows the level of interaction and network, which occurs between players during the offensive phase of the game.

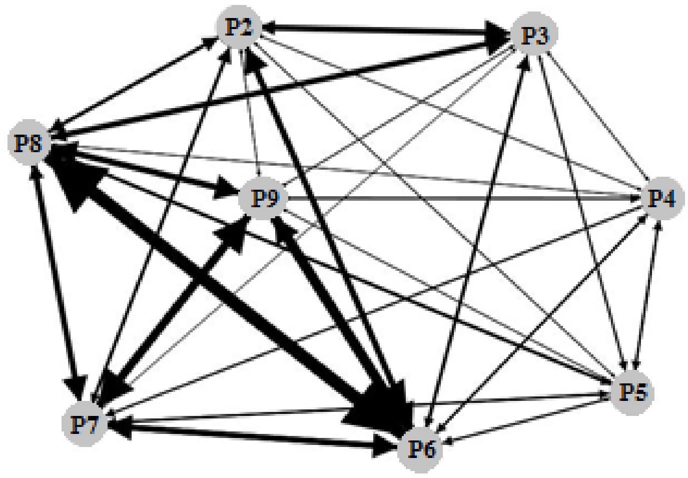
As a complement to network analysis, and to further understand where the interactions presented in Table 1 and Figure 1, occur a schematic representation of ball transmission performed by different players in the different rink zones and subzones is shown in Figure 2. To that end, a matrix similar to the one presented in Table 1 was built, but this time, considering a double entry of passes made and received under each sector of the field.

A greater predominance of interactions was noted in the offensive midfield, especially at sector 4 (4L-4R; 4R-4L); at the lateral corridors (4L-5L; 5L-4L; 4R-5R; 5R-4R); and, in the finalization zone (5C). Although less pronounced, Figure 2 also shows a high number of interactions in the following zones: 4C-4E; 4C-4D; 4L-6L; 6L-4L; 4R-6R; 6R-4R; 5R-5R; 5L-5C; 5C-5L; 5R-5C; 5C-5R; 6L-5C.

Table 1. Network register – interaction of pass actions between players (offensive team actions)

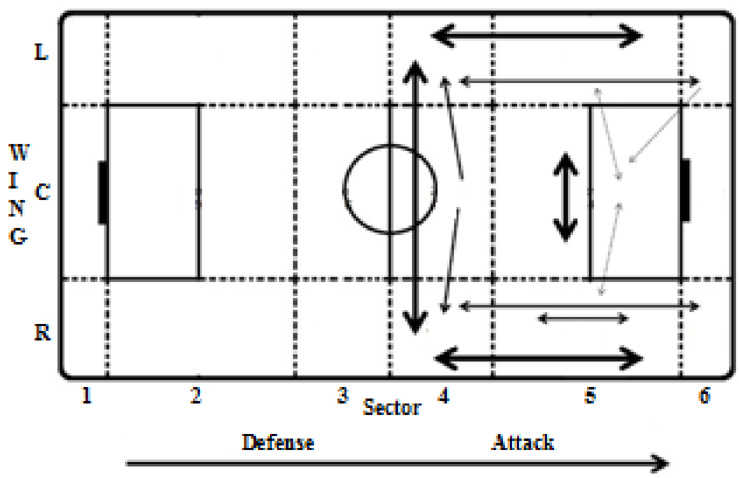
Of / To	P2	P3	P4	P5	P 6	P7	P8	P9	IM
P2	-	32	5	4	33	16	28	9	127
P3	21	-	4	18	12	0	24	6	85
P4	3	6	-	14	10	11	6	5	55
P5	5	9	14	-	14	12	23	8	85
P6	36	22	10	8	-	33	61	35	205
P7	20	1	7	10	36	-	23	43	139
P8	28	31	5	14	62	34	-	30	204
P9	7	2	12	9	27	45	37	-	139
IR	120	103	57	77	194	151	202	135	1039
TI	247	188	112	162	399	290	406	274	-

Legend: To = interaction received by player; Of = interaction performed by player; P = Player; IM = Interactions made; IR = Interactions received; TI = Total of interventions.



Legend: Arrows thickness illustrates the number of interaction between pairs of players

Figure 1. Level of interaction and network between players on offensive phases of the game



Legend: L = Left; C = Central; R = Right

Figure 2. Transmission of the ball done by players, and interactions zones of the team

Table 2. Probability of interaction between players

Of /To	P2	P3	P4	P5	P6	P7	P8	P9
P2	-	0,25	0,04	0,03	0,26	0,13	0,22	0,07
P3	0,25	-	0,05	0,21	0,14	0,00	0,28	0,07
P4	0,05	0,11	-	0,25	0,18	0,20	0,11	0,09
P5	0,06	0,11	0,16	-	0,16	0,14	0,27	0,09
P6	0,18	0,11	0,05	0,04	-	0,16	0,30	0,17
P7	0,14	0,01	0,05	0,07	0,26	-	0,17	0,31
P8	0,14	0,15	0,02	0,07	0,30	0,17	-	0,15
P9	0,05	0,01	0,09	0,06	0,19	0,32	0,27	-

Legend: To = interaction received by player; Of = interaction performed by player; P = Player.

Table 2 shows a probability of interaction between players.

Assuming that a probability of an interaction that is not likely to be achieved was 0, and the probability of an achievable interaction corresponded to the value 1, the current results show that there's a probability of occurring an interaction above 0,25, between the following players: player 9 and 7 (0,32); player 7 and 9 (0,31); player 8 and 6 (0.30); player 6 and 8 (0,30); player 3 and 8 (0,28); player 5 and 8 (0,27); player 9 and 8 (0,27); player 2 and 6 (0,26); player 7 and 6 (0,26); player 3 and 2 (0,25); player 2 and 3 (0,25); player 4 and 5 (0,25).

Finally, Table 3 shows the global rank of interactions between players.

Table 3. Global rank of interaction between players

Rank	Pass actions made		Pass actions received	
	Player number i	g_i	Player number i	g_i
1st	8	0.6686	6	0.6673
2nd	6	0.6569	8	0.6568
3rd	7	0.5833	9	0.5667
4th	9	0.5551	7	0.5494
5th	2	0.5275	2	0.5200
6th	3	0.4517	3	0.4255
7th	5	0.3329	5	0.4043
8th	4	0.2945	4	0.3140

Player 8 ($g_8 = 0.6686$) and player 6 ($g_6 = 0.6569$) presented the highest global rank of the team in terms of promoted interactions. Moreover, player 6 ($g_6 = 0.6673$) and player 8 ($g_8 = 0.6568$) had the higher global rank of the team in terms of interactions passing through them.

4. Discussion

The purpose of this study was to identify the number of intra-team interactions and to examine which athletes have more interactions with their peers through the use of pass. A further aim was to examine the influence of interpersonal actions on competitive performance and the final result of the game. We analyzed the preferential connectivity levels of specific players, highlighting their interactions and identifying those who had the greatest influence on ball movement. In that sense, results show that the centroid player can be considered as the player who maintains the interaction of the whole team [17-19].

Considering the results of recent studies of network analysis [10, 25], there's a need to understand the intra and inter-individual behaviours that are associated with team sports. They can emerge not only from actions and strategies of individual players, but also from group tactical decisions that influences the performance of the players in the game [19, 21]. Therefore, players have to self-organize their performance to overcome game's "constraints" (e.g., adversary, public, etc.) and help the team to succeed [10, 14].

While more data on individual and group level are required to drawn definitive conclusions, the results of this study are new insights to the understanding of the roller hockey game. In fact, our results describe precisely the player's level of interaction and network between players on offensive phases of the game.

Regarding the zones of preferential interaction used by players during the offensive phase, we observed that there is a predominance of offensive midfield interactions, particularly in the right and left side of the sector 4 (4L-4R; 4R-4L). The same trend was noted for longitudinal observation of midfield side corridors (4L-5L; 5L-4L; 4R-5R; 5R-4R) and for the finalization zone (5C). It is worth noting that the observed trend of ball movement tended to be in the beginning of offensive midfield and inside corridors.

The results extend previous findings demonstrating that that some players tend to preferably interact with certain players in certain areas of the rink. Therefore, the results put forward in this paper suggest a stronger connectivity between some players against others, which is consistent with previous research in team ball sports [17-19]. In this sense, there are some issues that deserve our attention, namely: why is this type of interaction characteristic of certain players? What are the reasons underling those occurrences? Is this agame model imposed by coach? Is this a self-organized process that acts independently without external feedback, in which players interact as a dynamic system?

While acknowledging these questions, McGarry et al.'s [14] study, suggest the existence of an "attractor" or preferred state that influences the coordinative structure of the team along with its competitive performance. Additional studies are needed to critically obtain contextual information from players through the possibilities of game (affordances), verifying the extent to which this information may or may not influence actions of the actors on the ground [6, 25].

Although there are no studies in roller hockey that allow us to compare the present data, works devoted to basketball and soccer (e.g., [3, 7, 9]), found similar game-related statistics and patterns. Therefore, we can assume that this approach can be useful to measure tactical performance in youth roller hockey players.

The centroid analyzes represented an essential resource bridging the gap between collective behavior and the flow of the game [8]. This study also shows that the collective dynamics of this youth roller hockey team includes numerous episodes and instances of cooperation, which act in a multidimensional perspective. Accordingly, future research should focus not only the number of interactions that occur in a given space and time period, but also to establish the dynamic pattern of teams' coordination in the course of individual and collective actions.

Traditional notational analysis is essentially a means of recording events so that there is an accurate and objective record of what actually took place [4]. It's undoubtedly importance in the range of match analysis techniques, can be complemented with the present qualitative assessment method. The present approach makes it possible the identification of player´s performance and the team game dynamics pattern for the observable coordinative structure [14, 19, 27].

5. Conclusions

Considering the number of intra-team interactions and the preferential connectivity levels, results showed that player 8

($g_8 = 0.6686$) and player 6 ($g_6 = 0.6569$) presented the highest global rank of the team in terms of promoted interactions. Generally, these results permitted the identification of the centroid player and his role in a team activity.

Given the above, it was concluded that roller hockey could be described as an open system able to create clusters of connectivity between players.This is something that can be applied to other team sports, such as football, handball or basketball, because through this network of interactions, coaches can further understand the team dynamics and optimize its performance to the objectives to be achieved during competition. The herein presented findings may help coaches and sport scientists to better understand how the collective behaviour is orchestrated.

6. Practical Application

This study has practical implications for coaches since it proposes a multidimensional analysis of the roller hockey. Such analysis of professional roller hockey matches is carried out through inter-player interactions (networks), in order to identify the centroid player and his central role in the team collective dynamics.

Furthermore, such an approach can be complemented with other indicators and other methods in order to increase the explanatory power of the variables presented in this study. For this purpose, one should further analyse these and other sport performance indicators in professional roller hockey teams, transversal to other team sports, using, for this intent, a robust and larger sample in terms of number of games and players.

ACKNOWLEDGEMENTS

This research was supported by the Portuguese Foundation for Science and Technology (FCT) under the grant SFRH/BPD/99655/2014. JVdS was partially supported by a grant from the Portuguese Foundation for Science and Technology: SFRH/BPD/100470/2014.

REFERENCES

[1] Albert. R, and Barabasi. A. L., 2000, Topology of evolving networks: local events and universality, Physical Review Letters, 85, 5234-5237.

[2] Barabási. A, and Oltvai. Z., 2004, Network biology: understanding the cell's functional organization, Nature Genetics, 5, 101-113.

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

[4] Carling, C. Williams, M. and Reilly, T., 2005, Handbook of soccer match analysis. A systematic approach to improving performance, London: Routledge.

[5] Davids, K. Bennett, S. J. and Newell, K. M., 2006, Movement system variability, Champaign, Illinois: Human Kinetics Publishers.

[6] Duch, J. Waitzman, J. S. and Amaral, L. A. N., 2010, Quantifying the performance of individual players in a team activity, PLoS ONE, 5, e10937.

[7] Folgado, H. Lemmink, Koen A. P. M. Frencken, W, and Sampaio, J., 2014, Length, width and centroid distance as measures of teams tactical performance in youth football, European Journal of Sport Science, 14(1), S487-S492.

[8] Frencken, W. and Lemmink, K., 2008, Team kinematics of smallsided soccer games: A systematic approach, In Reilly, T. and Korkusuz, F. (Eds.), Science and soccer VI, 161-166. London: Routledge.

[9] Frencken, W. Lemmink, K. Delleman, N. and Visscher, C., 2011, Oscillations of centroid position and surface area of soccer teams in small-sided games, European Journal of Sports Sciences, 11(4), 215-223.

[10] Gama, J. Passos, P. Davids, K. Relvas, H. Ribeiro, J. Vaz, V. and Dias, G., 2014, Network analysis and intra-team activity in attacking phases of professional football, International Journal of Performance Analysis in Sport, 14, 692-708.

[11] Horvath, S. 2011, Weighted Network Analysis: Applications in Genomics and Systems Biology, London: Springer.

[12] Hughes, M. 1996, Notational Analysis, In Reilly, T. (Ed.), Science and soccer, 343-361. London: E and FN Spon.

[13] Kingman, J. C. and Dyson, R. J., 1997, Player position, match half and score effects on the time and motion characteristics of roller hockey match play, Journal of Human Movement Studies, 1, 15-29.

[14] McGarry, T. Anderson, D. Wallace, S. Hughes, M. and Franks, I., 2002, Sport competition as a dynamical self-organizing system, Journal of Sports Sciences, 20, 771-781.

[15] Mendo, A. H. and Argilaga, M. T., 2002, Behavioral structure in sociomotor sports: Roller-hockey, Qualitative & Quantitative, 36, 347-378.

[16] Newman, J. 2003, Random graphs as models of networks, In Bornholdt, S. and Schuster, H. G. (Eds.), Handbook of graphs and networks, 35-68. Berlin: Wiley-VCH.

[17] Passos, P. Araújo, D. Davids, K. Gouveia, L. and Serpa, S., 2006, Interpersonal dynamics in sport: The role of artificial neural networks and three-dimensional analysis, Behavior Research Methods, 38, 683-691.

[18] Passos, P. Araújo, D. Davids, K. Gouveia, L. F. Milho, J. and Serpa, S., 2008, Information-governing dynamics of attacker defender interactions in youth rugby union, Journal of Sport Sciences, 26, 1421-1429

[19] Passos, P. Davids, K. Araújo, D. Paz, N. Minguéns, J. and Mendes, J., 2011, Network as a novel tool for studying team ball sports as complex social system, Journal of Sports Sciences and Medicine, 14, 170-176

[20] Peebles, P. Z. 2001, Probability, random variables, and random signal principles, McGraw-Hill.

[21] Perl, J. and Weber, K., 2004, A neural network approach to pattern learning in sport, International Journal of Computer Science in Sport, 367-70.

[22] Ravasz, E. Somera, A. L. Mongru, D. A. Oltvai, Z. N. and Barabasi, A. L., 2002, Hierarchical organization of modularity in metabolic networks, Science, 297, 1551-1555.

[23] Reilly, T. and Gilbourne, D., 2003, Science and football: a review of applied research in the football codes, Journal of Sports Sciences, London, 2003; 21: 693-705.

[24] Strøyer, J. Hansen, L. and Klausen, K., 2004, Physiological profile and activity pattern of young soccer players during match play, Medicine & Sciencein Sports & Exercise, 36 168-74.

[25] Vaz, V. Gama, G. Valente dos Santos, J. Figueiredo. A, and Dias, G., 2014, Network: Análise da Interação e Dinâmica do Jogo de Futebol, Revista Portuguesa de Ciências do Desporto, 14(1), 12-25.

[26] Wasserman, S. and Faust, K., 1999, Structural analysis in social the social sciences series: social network analysis, methods and applications, Cambridge: Cambridge University Press.

[27] Williams, M. Lee, D. and Reilly, T., 1999, A quantitative analysis of matches played in the 1991 – 92 and 1997 – 98 seasons, London: The Football Association.

[28] Yamamoto, Y. and Yokoyama, K., 2011, Common and Unique Network Dynamics in Football Games, PLoS ONE, 6, e29638.