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NETWORKS AND CENTROID METRICS FOR UNDERSTANDING FOOTBALL

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ABSTRACT

This study aimed to verify the network of contacts resulting from the collective behaviour of professional football teams through the centroid method and networks as well, thereby providing detailed information about the match to coaches and sport analysts. For this purpose, 999 collective attacking actions from two teams were analysed, including passes completed, passes received and crosses, involving a total of 2 335 intra-team interactions (1 160 passes and crosses performed and 1 175 ball receptions). Amisco® software was used to characterise the collective behaviour of professional football teams. The results showed that the interaction of the centroid players in the offensive phase of the game occurred, preferably, through the formation of vertices that were connected by links, which were mainly orchestrated by the action of centroid players. It was concluded that the interactions of the professional football teams tended to occur preferentially on the offensive phase of the game, and the network of contacts was controlled, mainly, in ball possession, through passes performed in the central and lateral areas of the field. The herein presented findings may help coaches and sport scientists to understand better, how self-organisation emerges and how collective behaviour is orchestrated.

Key words: Football; Centroid players; Interpersonal interactions; Network analysis; Collective behaviour.

INTRODUCTION

Researchers, such as Frencken and Lemmink (2008) and Folgado *et al*. (2014), have been describing the usefulness of the centroid method and its practical applications in the context of Sport Science. Following the same line of thought, Lames *et al*. (2010) indicated that similar principles might underpin the collective organisation of teams' centroids in invasion games. However, it seems that the centroid metric, supported only by the position of players in the field, may not be sufficient to show the true essence and dynamics of the football game (Bartlett *et al*., 2012). Therefore, to resist this "limitation", the network methodology might be useful to shed light on the contributions of a key individual performer to team performance. Additionally, provide insights on how creative and organised individuals might act to orchestrate team strategies (Gama *et al*., 2014). Moreover, network analysis can support

the investigations of continuous interactions between players and teams during competitive performance. This methodology can be used to characterise the collective behaviours that emerge through cooperation and competition between players during competitive football matches (Duch *et al*., 2010).

PURPOSE OF THE STUDY

Bearing these ideas in mind, the aim of this study was to decode the network of interactions resulting from the collective behaviour of professional football teams by benefiting from both centroid and network approaches, to provide more detailed information about game events and situations that precede the game to coaches. Therefore, this study sought to record and characterise the offensive effectiveness of professional football teams using centroid and network analysis.

METHODOLOGY

Selection of teams and matches

Two matches between the top 2 teams from the Portuguese Premier League, 2010/2011, were selected. Additionally, 999 collective attacking actions (involving ball possession) from both teams were analysed, including passes completed, passes received and crosses, involving a total of 2 335 intra-team interactions (1 160 passes and crosses performed and 1 175 ball receptions). The data was analysed using the *Match Analysis Software Amisco®* (version 3.3.7.25), which is a specialised programme that allows to characterise the activity profiles of the team (Gama *et al*., 2014).

Procedures for analysis of data

Using the Amisco® software, the networks and intra-team connectivity matrices were constructed, displaying and measuring the interpersonal relationships established by the players. A major focus of this study was to analyse which areas of the field were occupied by centroid players during the football matches (Gama *et al*., 2014). For the purpose of quantifying the frequency of relevant events, such as collective actions like passes, crosses and passes received, a notational analysis of competitive performance of the team during offensive phases was performed. An interaction was established whenever a player with the subsequent reception of the ball performed a pass or a cross by a teammate (Gama *et al*., 2014).

The football field presented in Figure 1 was validated using Amisco® software, which automatically divides the field into 24 areas, composed of 4 corridors and 6 sectors. The average positioning was calculated by recording the total number of ball contacts achieved by each player (player position was calculated each time he touched the ball). Thus, the average positioning of each player was related to the number of times and the field location where he contacted the ball (Duch *et al*., 2010; Gama *et al*., 2014).

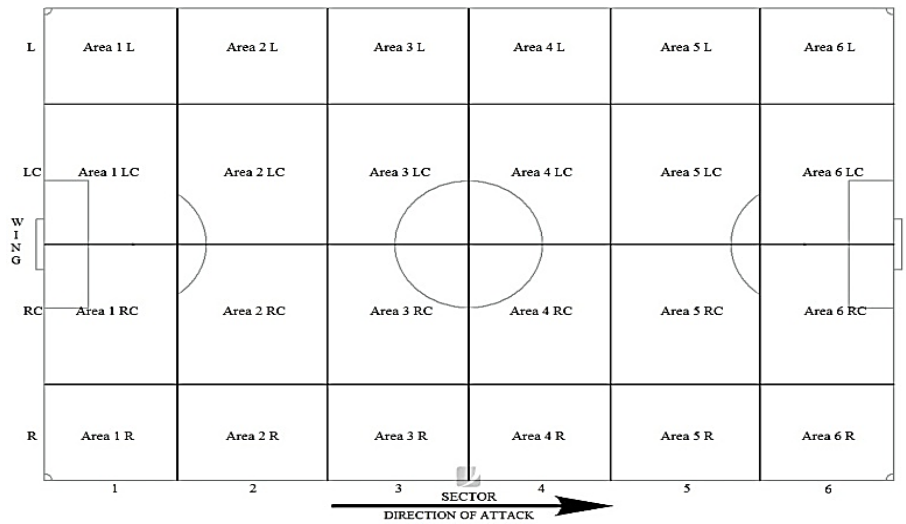


Figure 1. **FOOTBALL FIELD DIVIDED INTO 24 AREAS**

(Adapted from Amisco® and Gama *et al*., 2014:696).

The data was represented by a non-symmetrical weighted adjacency matrix $A_w = [w_{ij}] \in \mathbb{R}^{n \times n}$, where n is the number of players in the team. The upper-triangle of A_w 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, that is the values are undefined for $i = j$). 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 a player, namely, $w_{ij} \neq w_{ji}$ (Clemente *et al*., 2014). To understand better the network of interactions, which emerge from players of the same team, the relative frequency probability method was considered (Peebles, 2001):

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

wherein $p(w_{ij})$ is the probability of a given interaction w_{ij} to occur between Player i and Player j. It should be noted that the probability of an interaction to occur results in a relative frequency of occurrence, such that $0 \leq p(w_{ij}) \leq 1$. Besides the probability of interaction between pairs of players, an intra-player network concept (network property of a node), denoted as the *centroid players*, was also considered. To compute this network concept, one can create a new relative weighted adjacency matrix $A_r = [r_{ij}] \in \mathbb{R}^{n \times n}$, defined as:

$$r_{ij} = \begin{cases} \frac{w_{ij}}{\max\limits_{i \neq j} A_w} & , i \neq j \\ undefined & , i = j \end{cases} \tag{2}$$

where $0 \leq r_{ij} \leq 1$ for $i \neq j$, with $i\, j = 1, \ldots, n$. Note that for matrix A_w, matrix A_r is undefined when $i = j$ as a given player cannot interact with itself.

The denominator $\max_{i \neq j} A_w$ corresponds to the larger connectivity between players, namely the pair of players interacting the most together. Note that, as the weighted adjacency matrix A_w, A_r is also not symmetrical. Afterwards, one needs to compute a widely used concept for distinguishing or classifying a vertex of a network (Horvath, 2011), 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 makes, but may not present a high connectivity with the team regarding the pass actions he receives. The most cooperative player or players, can be found by finding the index/indices of the maximum connectivity for 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 a player. In team sport contexts, 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 still be unable to produce consensus among his non-direct teammates. Therefore, the *clustering coefficient* of Player i offers a measure of the degree of inter-connectivity in the neighbourhood of Player i, being defined as:

$$c_i = \frac{\sum_{k \neq i} \sum_{j \neq k, j \neq i,} r_{ik} r_{kj} r_{ji}}{(\sum_{k \neq i} r_{ik})^2 - \sum_{k \neq i} (r_{ik})^2} \quad (6)$$

such that $c = [c_i] \in \mathbb{R}^{1 \times n}$ is the vector of the clustering coefficient of a player (Ravasz & Barabási, 2003). As a team sport 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 players. Note that there will be a vector for the pass actions made and another for the pass actions received. Furthermore, the scaled connectivity s_i was chosen over the unscaled $k_{i,}$ since it lies

between 0 and 1 as the clustering coefficient $0 \leq g_i \leq 1$. Taking into account that the main objective of the football team, as any other collective sport, is to give priority to the collective performance (the overall interaction between players), one can contemplate a balanced consideration of $\rho_s = \rho_c = 0.5$. The top-ranked players, namely the ones presenting the higher g_i, will then be denoted as the *centroid players*. Within team sport, the *centroid players* could be considered as the players who maintain the connectivity of the whole team (Clemente *et al*., 2014). The centroid players are fundamental in the self-organisation process of the team, since they exhibit a higher level of quality during both execution and reception of passes, thereby contributing to a high intensity and density of the network of contacts established during the game. These players may contribute to a greater intensity and density of the contact network throughout the game. In order to compare easily the difference between successful and unsuccessful passes performed by a team in each of the 24 areas, according to game venue (games played home or away), a histogram-based analysis in the form of a *heat map* was carried out.

RESULTS

Game 1

The networks observed portrayed the interactions established between players of the same team through their distribution on the field during an offensive phase. Each player was assigned with an edge (arrow) connected to another player, with whom they engaged in an interaction, allowing the recording of the total number of interactions performed between the 2 players (Gama *et al*., 2014). In that sense, Table 1 shows 716 intra-team interactions (successful passes and crosses) between players of Team A. Table 2 shows the total amount of interactions between the players of Team B, in the first game. Player 5 interacted most with other players on Team A, engaged in a total of 99 interactions (51 passes and crosses; 48 ball receptions). Moreover, the highest level of interaction occurred between Player 21 and Player 12, with a total of 15 passes and crosses.

Table 1. **GAME 1: CENTROID VALUES FOR EACH PLAYER OF TEAMS A & B**

	Team A					Team B			
	Passes and crosses		Ball receptions			Passes and crosses		Ball receptions	
Rank	Player ^{i}	g_i	Player ^{i}	g_i	Rank	Player ^{i}	g_i	Player ^{i}	g_i
1st	5	0.5866	21	0.5697	1st	6	0.5954	4	0.5665
2nd	8	0.5023	5	0.4935	2nd	4	0.5472	17	0.5539
3rd	4	0.4242	12	0.4759	3rd	17	0.4999	14	0.5396
4th	17	0.4208	8	0.4616	4th	14	0.4419	6	0.4734
5th	1	0.3966	14	0.4430	5th	8	0.3723	10	0.4299
6th	14	0.3960	6	0.4418	6th	23	0.3592	23	0.4266
7th	6	0.3924	7	0.4102	7th	18	0.3453	8	0.3536
8th	7	0.3750	4	0.3584	8th	10	0.3450	18	0.2658
9th	9	0.3544	1	0.3270	9th	12	0.3231	12	0.2384
10th	21	0.3345	9	0.3245	10th	27	0.2980	31	0.2222
11th	12	0.3239	28	0.2918	11th	20	0.2364	27	0.1925
12th	28	0.3212	17	0.2881	12th	15	0.1268	20	0.1914
13th	19	0.2550	19	0.1210	13th	31	0.1236	15	0.0651
14th	18	0	18	0	14th	5	0.0217	5	0.0001

Table 2. **TEAM A: TOTAL AMOUNT OF INTERACTIONS* BETWEEN PLAYERS IN FIRST GAME**
(*Passes or crosses with receptions of ball)

Game time	Position	To/Of	1	4	5	14	21	6	7	8	9	12	17	28	19	18	
97	GR	**1**	–	1	3	6	3	1	0	0	0	1	0	0	0	0	
97	DC	**4**	6	–	6	4	3	5	1	0	0	0	0	0	0	0	
97	DE	**5**	10	10	–	2	1	7	2	6	0	1	3	4	1	0	
97	DC	**14**	3	4	4	–	10	4	2	3	0	2	0	1	0	0	
97	DD	**21**	2	0	2	12	–	1	4	3	1	2	2	0	0	0	
91	MC	**6**	2	5	4	2	2	–	4	3	0	0	3	3	0	0	
82	MC	**7**	0	0	6	0	3	3	–	3	3	7	2	0	0	0	
97	MC	**8**	0	6	5	4	3	5	2	–	6	2	4	2	0	0	
97	PL	**9**	0	0	5	0	2	2	3	6	–	4	0	1	0	0	
97	ED	**12**	0	0	2	1	15	0	9	3	3	–	0	1	1	0	
86	EE	**17**	0	1	7	2	0	2	2	13	2	2	–	0	0	0	
14	S	**28**	1	2	6	0	0	0	0	4	2	0	0	–	1	0	
10	S	**19**	0	1	1	0	0	0	0	0	0	0	0	2	–	0	
6	S	**18**	0	0	0	0	0	0	0	0	0	0	0	0	0	–	**Tot.**
Passes and crosses			24	30	51	33	42	30	29	44	17	21	14	14	3	0	352
Ball receptions			15	25	48	33	29	28	27	40	23	35	31	26	4	0	364
TOTAL of interactions			39	55	99	66	71	58	56	84	40	56	45	40	7	0	716

To= Interaction received by player Of= Interaction made by player
Rows display number ball receptions by each player ***Columns*** display number of passes or crosses performed by each player
GR= Goalkeeper; DC= Central Defender; DD= Right Defender; DE= Left Defender; MC= Central Midfielder; ED= Right Wing; EE= Left Wing; PL= Striker; S= Substitute

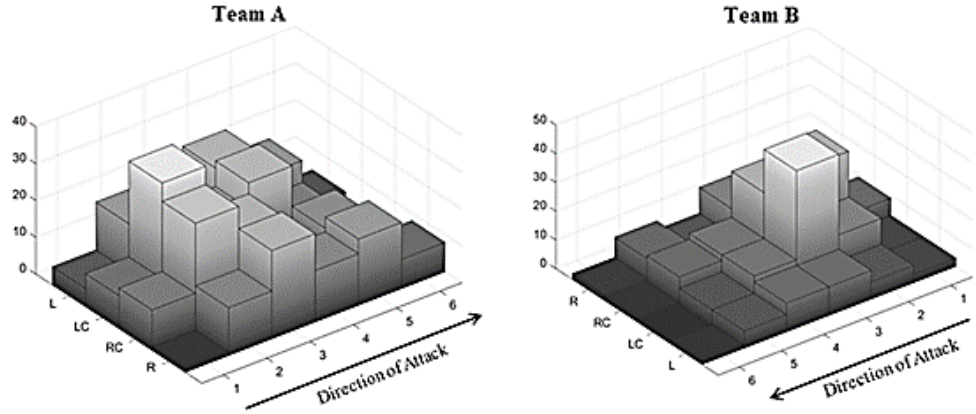
Table 3. **TEAM B: TOTAL AMOUNT OF INTERACTIONS* BETWEEN PLAYERS IN FIRST GAME**
(*Passes or crosses with receptions of ball)

Game time	Position	To/Of	12	4	23	27	6	10	17	18	8	14	31	20	15	5	
97	GR	**12**	–	2	3	0	1	1	1	1	0	0	0	0	0	0	
69	DC	**4**	4	–	1	4	3	0	6	1	2	14	0	1	0	0	
97	DE	**23**	0	2	–	2	7	3	4	3	0	0	0	1	0	0	
47	DC	**27**	1	3	2	–	1	0	0	1	0	0	0	0	0	0	
97	MCD	**6**	3	9	5	2	–	4	6	0	1	1	0	1	0	2	
97	MCO	**10**	0	1	1	0	3	–	3	2	2	5	4	1	0	0	
75	MC	**17**	0	4	2	1	10	7	–	3	1	5	1	1	0	0	
97	ME	**18**	1	1	7	4	4	0	2	–	0	0	1	1	1	0	
82	MCD	**8**	0	4	1	0	3	3	3	0	–	4	0	0	0	0	
97	DD	**14**	0	12	0	0	3	1	4	0	1	–	2	0	0	0	
97	PL	**31**	0	0	0	0	0	2	0	2	0	1	–	1	1	0	
49	S	**20**	0	2	0	0	2	2	1	3	0	0	2	–	0	0	
21	S	**15**	0	0	1	0	2	0	0	0	0	0	0	0	–	0	
14	S	**5**	0	0	0	0	0	0	0	0	0	0	1	0	1	–	**Tot.**
Passes and crosses			9	40	23	13	39	23	30	16	7	30	11	7	3	2	253
Ball receptions			9	36	22	8	34	23	35	22	18	23	7	13	3	2	255
TOTAL of interactions			18	76	45	21	73	46	65	38	25	53	18	20	6	4	508

To= Interaction received by player Of= Interaction made by player
Rows display number ball receptions by each player ***Columns*** display number of passes or crosses performed by each player
GR= Goalkeeper; DC= Central Defender; DD= Right Defender; DE= Left Defender; MCD= Defensive Midfielder; MCO= Offensive Midfielder; MC= Central Midfielder; MD= Right Midfielder; ME= Left Midfielder; PL= Striker; S= Substitute

Table 3 provides the centroid values for each player of Team A and Team B in the first game. The results reveal that Player 4 interacted most with other players on Team B. He engaged in a total of 76 interactions (40 passes and crosses; 36 ball receptions). In addition, the highest level of interaction occurred between Player 4 and Player 14 (14 passes and crosses performed). The centroid player was the most highly connected node in the network. Thus, from Team A, Player 5 presented the highest global rank for passes and crosses performed (0.5866), and Player 21 presented the highest global rank for ball receptions. On the other hand, from Team B, Player 6 achieved the highest rank for passes and crosses performed (0.5954), and Player 4 achieved the highest rank for ball receptions (0.5665).

Beyond quantification of the number of passes and crosses performed, it is worth noting where on the field (on average) the interactions were performed. Figure 2 displays the network providing a qualitative analysis of the main interactions performed (to which field location and between whom the passes were performed), based on the average field position of players. In addition to the collective connections performed between players, the relevance of centroid players from each team, particularly Player 5 (left defender) in Team A, and Player 4 (central defender) in Team B, is evident. Depending on the ball possession, Figure 3 identifies the location (areas) where the interactions were performed.

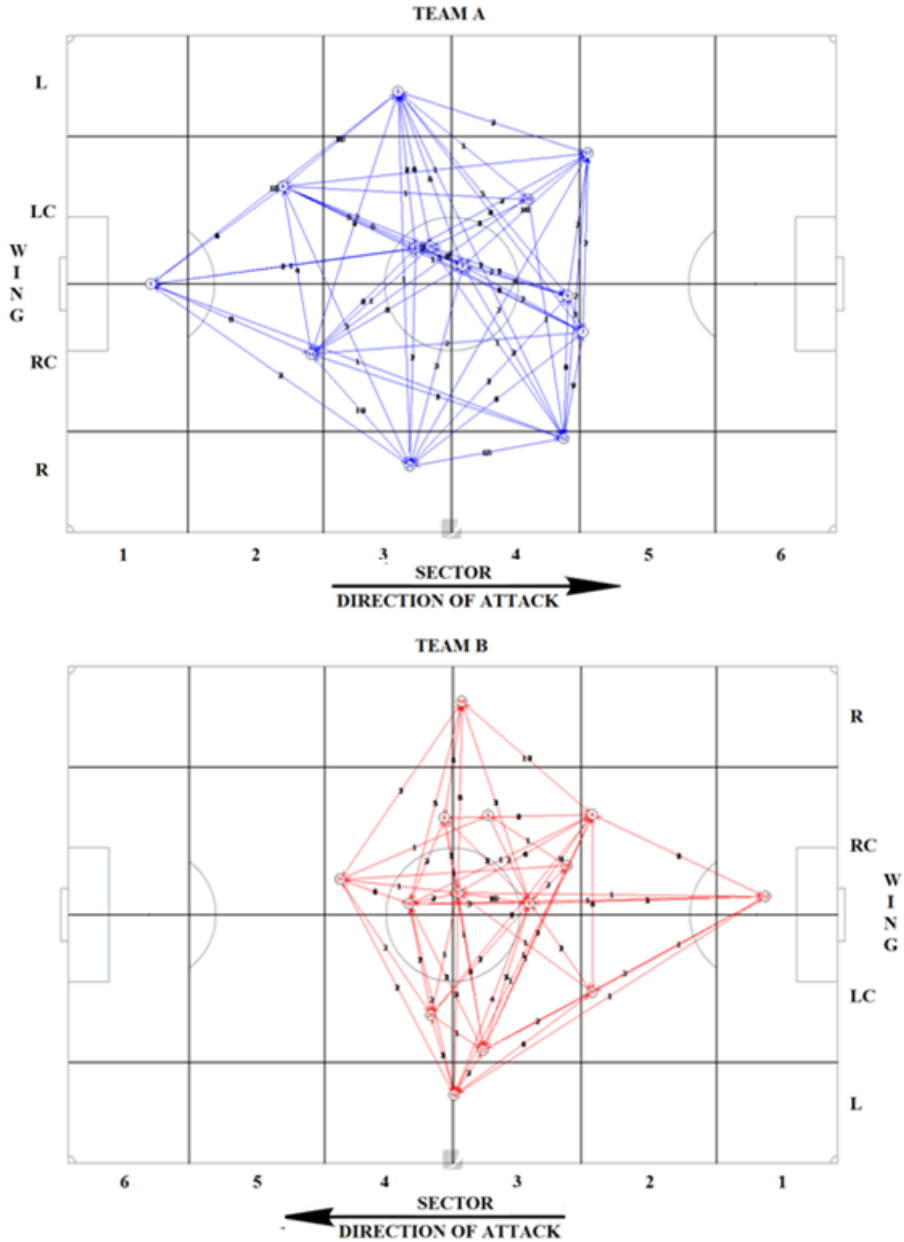


L= Left; LC= Left Centre; RC= Right Centre; R= Right.
Grey areas = Areas where largest number of passes and crosses occurred without success
Dark areas = Areas where there was less interaction between players.

Figure 2. **GAME 1: HEAT MAPS OF RELATIVE INTERACTIONS* BY TEAM A AND TEAM B IN THE FIELD**

(*Passes and crosses performed with ball receptions)

The heat maps show that Team A preferred performing in the defensive midfield, areas 2LC, 2RC and 4RC, while Team B mostly explored the defensive midfield, areas 3LC, 2RC and 3RC. Thus, while Team A explored all areas of the soccer field, Team B mainly set their game in defensive sectors.



L= Left; LC= Left Centre; RC= Right Centre; R= Right. Value of interaction is brought to the centre thereof.

Figure 3. **GAME 1: REPRESENTATIVE NETWORK OF INTERACTIONS* BETWEEN PLAYERS (TEAMS A & B) BASED ON FIELD LOCATION**

(*Performed and received)

Game 2

Table 3 shows 474 intra-team interactions between players of each football team.

Based on this, Player 8 interacted most with other players on Team A, with a total of 70 interactions (38 passes and crosses; 32 ball receptions). The highest level of interaction was observed between Player 13 and Player 12, with a total of 12 passes and crosses performed. The data shows that Team B performed a total of 638 intra-team interactions, resulting from 318 passes and crosses performed and 320 ball receptions (Table 4).

The player with the highest manifestation of interaction in Team B was Player 6, who presented a total of 79 interactions (41 passes and crosses performed; 38 ball receptions). Table 5 shows the centroid values for each player of both teams during the second game.

Table 3. **GAME 2: CENTROID VALUES FOR EACH PLAYER OF TEAMS A & B**

	Team A					Team B			
	Passes and Crosses		Ball Receptions			Passes and Crosses		Ball Receptions	
Rank	Player ^{i}	g_i	Player ^{i}	g_i	**Rank**	Player ^{i}	g_i	Player ^{i}	g_i
1st	8	0.6135	8	0.5863	1st	10	0.6057	18	0.5869
2nd	5	0.5516	12	0.5693	2nd	18	0.4694	10	0.5733
3rd	13	0.4955	13	0.5643	3rd	20	0.4565	11	0.5568
4th	17	0.4846	25	0.4744	4th	11	0.4485	4	0.5324
5th	25	0.4476	6	0.4149	5th	30	0.4200	20	0.4518
6th	12	0.4067	9	0.3964	6th	25	0.4046	8	0.4489
7th	7	0.3738	17	0.3391	7th	6	0.3984	30	0.4352
8th	9	0.3675	5	0.3328	8th	8	0.3830	12	0.3296
9th	1	0.3462	7	0.3213	9th	4	0.3632	6	0.3206
10th	6	0.3401	14	0.3007	10th	27	0.2796	2	0.3107
11th	30	0.2689	30	0.2210	11th	2	0.1994	25	0.2705
12th	14	0.2413	1	0.1193	12th	12	0.1050	27	0.2589
13th	4	0.0928	4	0.0541	13th	7	0.0943	33	0.1023
14th	10	0.0606	10	0.0270	14th	33	0.0263	7	0.0303

The data indicated that Player 8 from Team A achieved the highest rank for passes and crosses performed (0.6135), and received (0.5863). On the other hand, Player 10 from Team B achieved the highest rank for passes and crosses performed (0.6057) and Player 18 for ball receptions (0.5869).

Table 4. **TEAM A: TOTAL INTERACTIONS* BETWEEN PLAYERS IN SECOND GAME**

(*Passes or crosses with reception of ball)

Game time	Position	To/Of	1	5	13	14	30	6	8	25	9	12	17	7	4	10	
100	GR	**1**	–	0	0	3	0	0	1	0	0	1	0	0	1	0	
100	DE	**5**	4	–	0	0	3	2	4	4	1	1	1	1	1	0	
100	DD	**13**	1	0	–	4	0	0	8	4	1	6	0	3	0	0	
100	DC	**14**	3	1	3	–	0	1	0	2	0	0	0	0	0	0	
100	DC	**30**	4	2	0	0	–	2	0	2	0	0	0	0	0	0	
87	MC	**6**	1	3	2	0	2	–	4	3	2	4	2	0	0	0	
100	MC	**8**	1	4	5	0	1	0	–	5	3	5	6	2	0	0	
100	MC	**25**	1	1	2	1	0	2	7	–	1	0	3	0	1	0	
79	PL	**9**	0	4	4	2	0	1	3	2	–	3	0	0	0	0	
100	ED	**12**	2	0	12	2	1	1	3	3	5	–	1	1	0	1	
78	EE	**17**	0	8	1	1	1	3	5	3	0	0	–	0	0	0	
21	S	**7**	1	1	2	0	0	0	3	0	0	1	0	–	0	0	
21	S	**4**	0	1	1	0	0	0	0	0	0	0	0	0	–	1	
13	S	**10**	0	3	0	0	0	0	0	1	0	0	0	0	0	–	**Tot.**
	Passes and crosses		18	28	32	13	8	12	38	29	13	21	13	7	3	2	237
	Ball receptions		6	22	27	10	10	23	32	19	19	32	22	8	3	4	237
	Total of interactions		24	50	59	23	18	35	70	48	32	53	35	15	6	6	474

To= Interaction received by player Of= Interaction made by player

Rows display number ball receptions by each player ***Columns*** display number of passes or crosses performed by each player

GR= Goalkeeper; DC= Central Defender; DD= Right Defender; DE= Left Defender; MC= Central Midfielder; ED= Right Wing; EE= Left Wing; AV= Forward; S= Substitute

Table 5. **TEAM B: TOTAL INTERACTIONS* BETWEEN PLAYERS IN SECOND GAME**

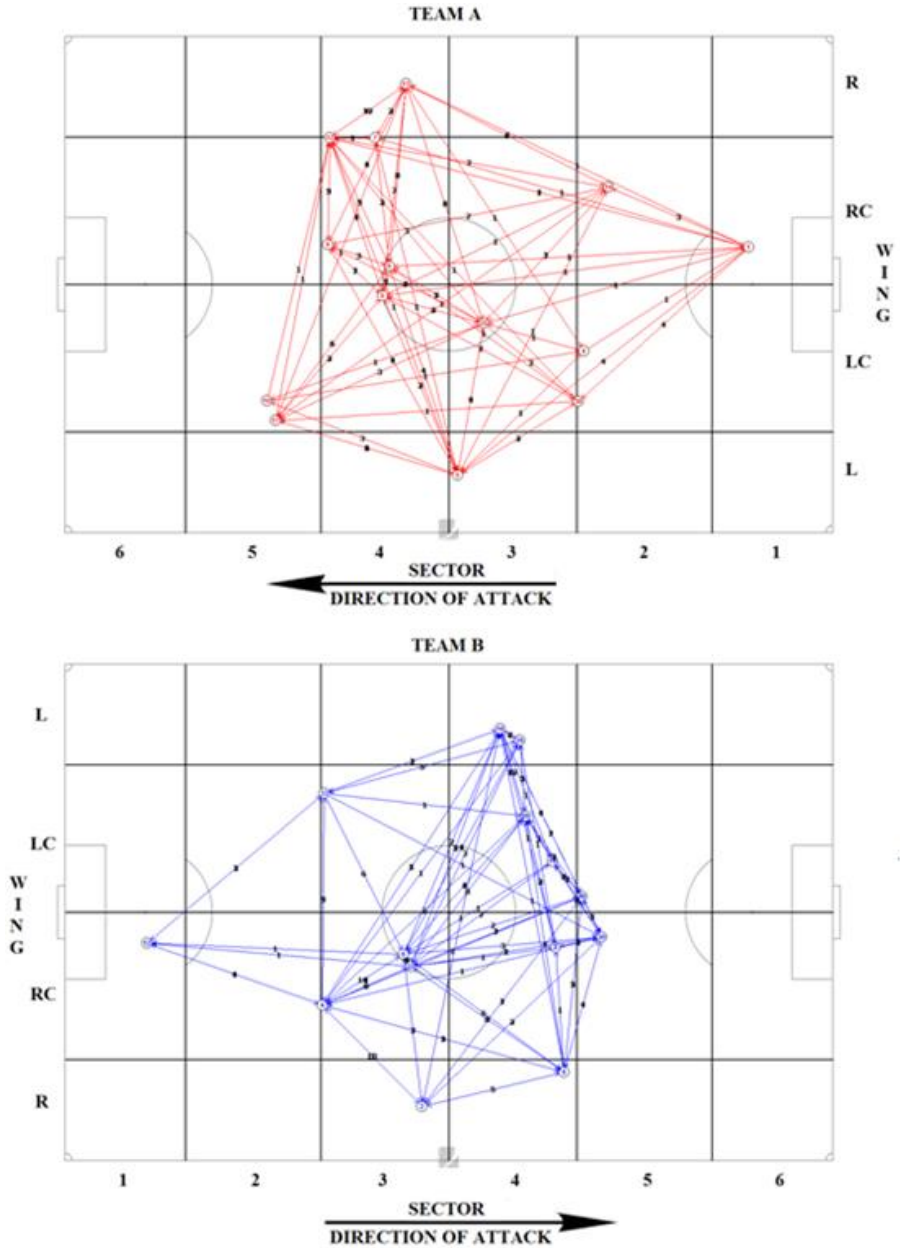
(*Passes or crosses with reception of ball)

Game time	Position	To/Of	12	4	18	2	27	6	10	20	8	11	30	25	7	33	
100	GR	**12**	–	4	0	0	1	1	0	0	0	0	0	0	0	1	
100	DC	**4**	1	–	3	3	9	10	1	0	1	0	1	0	0	5	
100	DE	**18**	0	1	–	1	2	2	1	6	1	0	1	7	1	1	
66	DD	**2**	0	10	2	–	0	3	1	0	5	0	2	0	0	0	
100	DC	**27**	0	8	5	0	–	9	1	0	3	0	1	2	0	0	
100	MCD	**6**	0	11	0	7	7	–	0	2	0	1	0	4	0	6	
50	MCO	**10**	0	0	4	2	2	2	–	3	2	2	1	0	0	0	
100	ME	**20**	0	2	12	0	8	4	2	–	4	1	2	2	2	1	
100	MD	**8**	0	3	0	5	6	6	5	0	–	0	4	0	1	0	
50	AV	**11**	0	0	1	0	2	0	1	1	0	–	3	0	0	0	
100	AV	**30**	0	0	2	3	2	3	3	4	4	1	–	1	1	1	
50	S	**25**	0	1	8	0	0	1	0	5	0	0	0	–	1	5	
41	S	**7**	0	0	1	0	1	0	0	3	1	0	2	0	–	0	
33	S	**33**	3	3	2	0	0	0	0	0	0	0	0	5	0	–	**Tot.**
	Passes and crosses		4	43	40	21	40	41	15	24	21	5	17	21	6	20	318
	Ball receptions		7	34	25	23	29	38	18	40	30	8	25	22	8	13	320
	Total of interactions		11	77	65	44	69	79	33	64	51	13	42	43	14	33	638

To= Interaction received by player Of= Interaction made by player

Rows display number ball receptions by each player ***Columns*** display number of passes or crosses performed by each player

GR= Goalkeeper; DC= Central Defender; DD= Right Defender; DE= Left Defender; MCD= Defensive Midfielder; MC= Central Midfielder; MD= Right Midfielder; ME= Left Midfielder; MCO= Offensive Midfielder; AV= Forward; S= Substitute



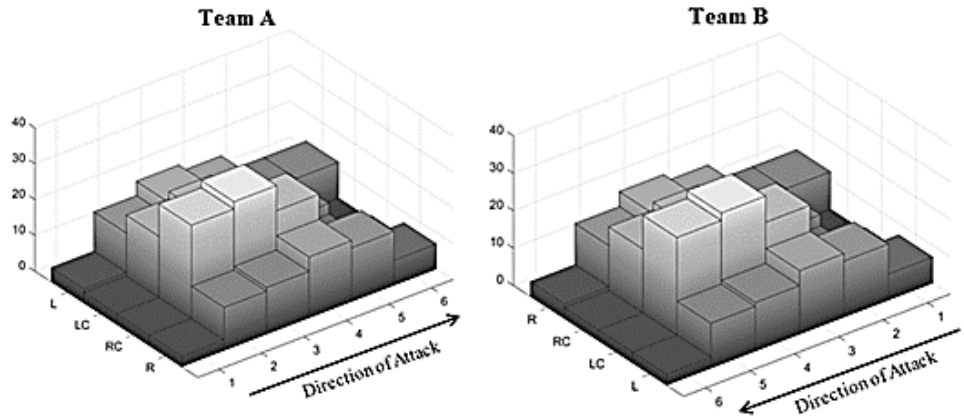
L= Left; LC= Left Centre; RC= Right Centre; R= Right. The value of the interaction is brought to the centre thereof.

Figure 4. **GAME 2: REPRESENTATIVE NETWORK OF INTERACTIONS* BETWEEN PLAYERS (TEAMS A & B) BASED ON FIELD LOCATION**

(* Performed and received)

In the second game, some behavioural differences, expressed for each team, were identified. For example, Team A kept exploring the offensives through an organised scheme and great rallies between players (positional attack). Figure 4 provides the location on the playing field where the interactions were observed for both teams during ball possession in all offensive phases.

The heat maps (Figure 5) indicate that both teams had a similar way to explore the offensive game, acting in all field areas, but with higher incidence in the central corridors. Team A acted mainly in the areas, 3RC, 2RC and 4RC, while Team B interacted mainly in 4LC, 5LC and 3LC.



L= Left; LC= Left Centre; RC= Right Centre; R= Right.
Grey areas = Areas where largest number of passes and crosses occurred without success
Dark areas = Areas where there was less interaction between players.

Figure 5. **GAME 2: HEAT MAPS OF RELATIVE INTERACTIONS* BY TEAM A AND TEAM B IN THE FIELD**

(*Passes and crosses performed with ball receptions)

DISCUSSION

The results present the centroid players who contributed the most to the overall connectivity of the team throughout the game. One can see that some other key-players, namely players who interacted the most but not throughout the game or with the whole team, were not always the centroid players. In fact, the centroid player was the player who maintained the overall connectivity of the whole team (Horvarth, 2011), and was considered as one of the most highly connected nodes in the network (Grund, 2012; Vaz *et al*., 2014).

Such evidence can be justified by the tactical approach of the players on the field, which was shaped and organised according to the behaviour and the actions of the opponent, as well as the strategy adopted by the coach (Gama *et al*., 2014). These players have an above average

quality of passing and receiving, therefore, contributing to a greater intensity and density of the contact network throughout the game (Duch *et al*., 2010; Lames *et al*., 2010).

Concurrent with the collective behaviour that was observed during the offensive phase, heat maps of relative interactions show all the relationships established by players and the areas that they mostly occupied. Hence, it was possible to measure objectively in which areas of the field the team acted and interacted more frequently (Gama *et al*., 2014).

Finally, these results indicate that an effective knowledge about the way that the opponent team proceeds in the offensive game phase could help to understand better, how self-organisation of the collective behaviour occurs (Folgado *et al*., 2014). For example, the data demonstrated that in both games Team A explored the offensive game in an organised way, promoting many rallies between players in order to maintain ball possession (positional attack), while in the first game Team B acted in an organised way contemplating ball possession and in the second game sought the opposing goal through a direct attacking game (fast attack and counter attack).

PRACTICAL APPLICATION

The findings of the present study may help coaches and sport scientists quantify the contributions and interactions of individual team members through analysis of their relevant actions in a team sport like football.

This study has practical implications for coaches, since it allows a multi-dimensional analysis of the football match. Therefore, professional football matches can be analysed through inter-player interactions (networks) in order to understand who the centroid player is and what his central role is in the collective team dynamics.

Moreover, this method consists of a potentially reliable option to measure the collective performance of the team and its players, which notational analysis appears not to provide robustly. From this perspective, here practical implications emerge again for coaches regarding the intra- and inter-individual performance trends, which results from playing actions, providing some answers about how teams self-organise their behaviour and performance. 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, it is suggested that further research analyse these and other indicators regarding sport performance in professional football teams, transversal to other sport teams, using a robust sample for this purpose from the standpoint of the number of games.

CONCLUSIONS

It was concluded that the intensity and density of this type of connectivity and the interaction nodes resulted through passes and crosses were successfully established during the games. Therefore, centroid players are fundamental in the self-organisation processes of the team, since they exhibit a higher level of quality during both execution and reception of passes, thereby contributing to a high intensity and density of the network of contacts established during a game. Finally, the network analysis showed that professional football teams attribute

particular importance to circulation and maintenance of ball possession, by passing to the centroid player several times.

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