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COMPARISON OF NETWORK PROCESSES BETWEEN SUCCESSFUL AND UNSUCCESSFUL OFFENSIVE SEQUENCES IN ELITE SOCCER

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DIOGO PEIXOTO[1], GIBSON MOREIRA PRAÇA[2], SARAH BREDT[2], FILIPE MANUEL CLEMENTE[1, 3]

[1] Polytechnic Institute of Viana do Castelo, School of Sport and Leisure, Viana do Castelo, Portugal
[2] Federal University of Minas Gerais, Belo Horizonte, Brazil
[3] Instituto de Telecomunicações, Covilhã, Portugal

ABSTRACT
Purpose. The study aimed to compare social network analysis (SNA) general measures and centrality levels of successful and unsuccessful offensive sequences performed by elite national teams in 64 matches of the FIFA World Cup 2014 tournament and to compare the level of centrality between playing positions.
Methods. Adjacency matrices of passing sequences within an offensive unit were built and treated in a dedicated SNA software.
Results. The main results indicated significantly lower values of total links and network density in successful sequences in comparison with unsuccessful ones in the teams that achieved the round of 8, semifinals, and the final. The comparisons between playing positions revealed that forwards showed the highest values of indegree centrality (balls received) and that midfielders presented the highest values of outdegree centrality (ball passed) in both successful and unsuccessful offensive units. Midfielders also exhibited the highest values of betweenness centrality (intermediation between teammates) in unsuccessful sequences and forwards in successful ones.
Conclusions. Greater cooperation among teammates may not be determinant for successful sequences. Forwards are the prominent players to receive the ball and intermediate the passing sequence in offenses that end in a goal.
Key words: graph theory, adjacency matrices, social network analysis, match analysis, football

INTRODUCTION

Football, as a team sport, employs the dynamics of small groups to reach a common objective [1]. This dynamics results from the interpersonal interaction amongst team members [2], who cooperate to create scoring opportunities and to prevent the opponent to score [1]. Some studies have found that successful passing is a key determinant in soccer performance and the ability of teams to retain ball possession is strongly correlated to success [3]. Moreover, successful teams display a higher number of connections (passes) between team members [4].

In the past few years, social network analysis (SNA) has been used as a match analysis technique [5, 6]. It indicates how teammates interact during the game (e.g., successful and unsuccessful offensive attempts) [7] and characterizes the individual and general properties of their interaction with the use of a digraph. Studies that applied SNA assessed differences between team playing styles [6, 8], identified the most eminent player in the team [9], presented the total number of connections in a game [6, 10], and investigated the influence of the obtained variables with team's whole performance (e.g., winning or losing, passing to the next round or being eliminated) [4]. However, one limitation of these studies is the poor description of how players behaved in specific moments of the game (e.g., fast-breaks) to create a scoring opportunity, that is, inadequate determination of what actions players per-

Correspondence address: Filipe Manuel Clemente, Instituto Politécnico de Viana do Castelo, Escola Superior de Desporto e Lazer, Complexo Desportivo e Lazer Comendador Rui Solheiro – Monte de Prado, 4960-320 Melgaço, Portugal, e-mail: filipe.clemente5@gmail.com

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formed that resulted in a goal. In this context, such SNA measures as centrality (i.e., *outdegree centrality* – the ability of a player to create ties with other teammates, and *indegree centrality* – a tendency of a player to be chosen by other actors) and *betweenness* (as team members 'in the middle' of the social network visualization probably play an important role in mediating passes between other teammates) could be used to discriminate between successful and unsuccessful offensive units (i.e., successful and unsuccessful shots on goal) [11]. These measures would give information about where in the field and to which player the first pass is made after retrieval of ball possession. These data would provide a better comprehension of a team playing style and the dynamics of offensive actions [12].

In addition, literature on SNA has shown differences among playing positions, such as centrality measures [5, 8]. In this context, midfielders were the most prominent players during the offensive process in soccer [8, 9]. However, few studies analysed the specific network properties of critical moments (e.g., before goals or shots on goal) [11]. This information might help coaches to better understand the relationships among players in these determinant moments of the game. On the basis of the abovementioned issues, this study aimed to compare (a) the network properties of successful and unsuccessful offensive sequences and (b) the network properties related to playing positions in successful and unsuccessful offensive sequences in the matches of the FIFA World Cup 2014 tournament.

MATERIAL AND METHODS

Sample

The total of 64 matches of the FIFA World Cup 2014 tournament were analysed. The sum of interactions between team members of all matches resulted in one sociomatrix and one network graph for each team per match, giving together 128 network graphs.

Data collection

All games played within the FIFA World Cup 2014 tournament were analysed. Only offensive sequences that resulted in shots or goals were studied. Players of the national teams were coded by numbers between 1 and 11, according to their position in the tactical lineup (GK: goalkeeper; ED: external defender; CD: central defender; MF: midfielder; EMF: external midfielder; FW: forward). In the case of player substitution, new numbers were provided according to the tactical position. If the team's tactical lineup was modified during the game, only the lineup that was applied most of the time was analysed. Team lineups were classified – one month apart – by 3 coaches with at least 5 years of experience in coaching football teams. The total number of passes within an offensive unit was used as the interaction criterion between team members and to create a sociomatrix for network analysis. Each pass between teammates was counted and coded in the sociomatrix according to the counted number (e.g., if there were 3 passes between players C and D, the number 3 was inserted in the sociomatrix). If there were no interactions between 2 players, the code zero (0) was inserted. The beginning of an offensive unit was determined by the retrieval of ball possession by a player of a team followed by a successful pass to a teammate. Offensive units were considered finished when a successful or unsuccessful shot on goal was performed. The reliability of the data was assessed with the Cohen's kappa test by adhering to a 20-day interval for re-analysis to avoid task familiarity issues [13]. When testing 15% of the full data, a kappa value of 0.76 was obtained. The value ensured a recommended margin for these kinds of procedures [13].

Network analysis

The Social Network Visualizer (SocNetV) was utilized to create all the 128 sociomatrices [14]. SocNetV is a graphical 'tool' that can be used to analyse the properties of social networks through mathematical graphs, according to the network data inserted. It also computes basic graph properties, such as total links and density, and more advanced structural measures, such as centralities and betweenness, which were applied in this study.

Network analysis of the 64 games in the FIFA World Cup 2014 tournament focused on 5 measures based on previous studies in this field [5, 6, 15]: (i) total links; (ii) network density; (iii) indegree centrality; (iv) outdegree centrality; and (v) betweenness.

General network measures

Total links

One adjacency matrix was originated for each team per each game of the FIFA World Cup 2014 tournament. In the adjacency matrix, the numbers represent the number of interactions that occurred between two players in an offensive unity (e.g., the number of passes from player C to player D was identified when the row of player C intercepted the column of player D, which gives the element (c, d) or the number of times that player C interacted with player D) [7].

The total number of passes that player C made to all other teammates was obtained by the sum of all elements of player C row in the adjacency matrix with the use of the following formula:

$$\sum_{c \neq d}^{11} (c, d)$$

This measure is called nodal outdegree and indicates the importance of a player for the outcome of the offensive unity, on the basis of the number of teammates who this player interacted with.

The total links were used to compare the unsuccessful and successful shots in all the 64 games of the competition because they indicate the total number of passes made amongst teammates while they were in an offensive unity. A high level of total links is bound with success, indicates the teams' cooperation level, and may also be correlated to offensive success.

Network density

In a directed graphic context, network density is established as the ratio between the total number of observed links among players (nodes) (represented by L in the equation below) and the total number of possible links. These graphs present a given number of nodes, indicated by letter n. In undirected graphs, possible pairs of nodes can reach the maximum number of $n(n–1)/2$ and the number of possible links is $n(n–1)/2$ (since the link (i, j) is considered the same as (j, i)) [7].

$$\Delta = \frac{L}{n(n-1)/2} \Leftrightarrow \frac{2L}{n(n-1)}$$

When working with ordered relations, as in the case of this study (interactions between teammates), the maximum number of possible directed links is defined by $n(n–1)$. By that, in this situation the density is computed by:

$$\Delta = \frac{L}{n(n-1)}$$

Density can assume a value between 0 and 1, where 0 represents the absence of links (edges) and 1 applies when all links are present. It has been suggested that in valued graphs or digraphs, density can be obtained through the average of the values that correspond to the edges across all edges [16]. Since only valued graphs were used in this study (one for each national team), it is possible to measure the average strength of the edges and use it to compute the network density, employing the equation:

$$\Delta = \frac{\sum w_k}{n(n-1)}$$

Indegree centrality

Indegree centrality (%IDC) and other centrality metrics have the common objective to find out the most prominent node (player) in a context. This metric depends only on the interactions between all nodes and a specific node. In a non-valued or directed graph $G(V, E)$, where V corresponds to a set of nodes and E to a set of edges, the %IDC is the total amount of inbound edges from all neighbour nodes that connected to a given node u. For weighted digraphs, the following equation is valid, where a_{vu} is the weight of $e_{vu} \in E$ [7]:

$$IDC'_u = \sum_{v=1, u \neq v}^{G} a_{vu}$$

By adding the elements that compose a given column of the adjacency matrix, it is possible to obtain the %IDC score of a node relative to that column, both in valued or non-valued graphs.

Only inbound links are considered when computing the %IDC index, which means that the nodes with higher %IDC scores represent the most requested players of the team during offensive moments. Therefore, high %IDC scores indicate the most important players in the offensive sequence (the most requested players, who experience an increased responsibility in the offensive process).

Outdegree centrality

In turn, outdegree centrality (%ODC) focuses on the outbound links (edges) made from a given node u to all other neighbour nodes, which can be obtained from weighted digraphs with the use of the following equation, where $A(u, v)$ is the (u, v) element of the adjacency matrix A [7]:

$$ODC_u = \sum_{v=1, u \neq v}^{g} A(u, v)$$

Therefore, the %ODC quantifies the activity of a node in an offensive unity. Higher %ODC scores indicate a higher level of activity and interactions (higher number of total links), suggesting an important role in the offensive process and a superior level of performance.

Betweenness centrality

Betweenness centrality (%BC) aims to determine the actor in the 'middle' of a social network (team) by considering the shortest paths amongst all sets of 2 nodes – it indicates how much control each node has over the network. This measure quantifies how often a player mediates interactions between teammates [7].

In an unweighted graph, G = (V, E), with n_i, n_j, $n_k \in V$, i, j, k = 1, …, n. The standardized %BC index can be calculated as follows [7]:

$$C'_b(n_k) = \frac{1}{(n-1)(n-2)} \sum_{\substack{n_i, n_j \in V \\ i \neq nj \neq k}} \frac{g_{ij}(n_k)}{g_{ij}}$$

where $g_{ij}(n_k)$ is the number of shortest paths between n_i and n_j that pass by n_k, and g_{ij} is the number of shortest paths between n_i and n_j. The calculation for weighted digraphs employs a similar equation [17].

Statistical procedures

The comparisons of general measures (total links and network density) and network centralities (%IDC, %ODC, and %BC) between the results of successful and unsuccessful offensive units (i.e., successful or unsuccessful), stages of competition (e.g., round of 8), and playing positions was tested with multivariate MANOVA, followed by a two-way ANOVA if significant interactions between factors were found. Independent t-tests were used to identify significant differences reported by the ANOVAs. Cohen effect size *d* was applied to calculate the magnitude of differences between conditions and was classified as no effect ($d \leq 0.41$), minimum effect ($0.41 < d \leq 1.15$), moderate effect ($1.15 < d \leq 2.70$), and strong effect ($d > 2.70$) [18].

A one-way ANOVA followed by Tukey HSD post-hoc test was used to compare network centralities between playing positions. Partial eta squared η^2 effect size (*ES*) served to calculate the magnitude of differences between positions and was classified as no effect ($ES \leq 0.04$), minimum effect ($0.04 < ES \leq 0.25$), moderate effect ($0.25 < ES \leq 0.64$), and strong effect ($ES > 0.64$) [18]. All analyses were performed in the SPSS software (version 23.0, USA). Statistical significance was set at 5%.

Ethical approval

The research related to human use has been complied with all the relevant national regulations, institutional policies and in accordance the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or equivalent committee.

RESULTS

General network measures

The multivariate MANOVA tested the variance between factors (successful or unsuccessful offensive units and stage of competition) and dependent variables (total links and network density). Significant differences were found between successful and unsuccessful units for general network measures ($p = 0.001$; $\eta_p^2 = 0.083$), as shown in Table 1. No significant differences were observed between stages of competition for general network measures ($p = 0.454$; $\eta_p^2 = 0.020$, *no effect*). No interactions existed between factors (successful or unsuccessful units * stage of competition) for network measures (Pillai's trace = 0.070; $p = 0.095$; $\eta_p^2 = 0.035$, *no effect*).

The independent t-test showed significantly lower values of total links in successful offensive units in the teams that achieved the round of 8 ($p = 0.033$; $d = 0.631$, *minimum effect*), semifinals ($p = 0.014$; $d = 1.158$, *moderate effect*), and the final ($p = 0.002$; $d = 1.587$) compared with unsuccessful units. The values of network density were significantly lower in successful than in unsuccessful offenses in the teams that achieved the round of 8 ($p = 0.031$; $d = 0.691$), semifinals ($p = 0.014$; $d = 1.114$, *minimum effect*), and the final ($p = 0.002$; $d = 1.578$, *moderate effect*).

Network centralities

The multivariate MANOVA compared the dependent variables %IDC, %ODC, and %BC among factors (successful or unsuccessful offensive units and playing positions), as shown in Table 2. Significant differences were found between successful and unsuccessful offensive units ($p = 0.001$; $\eta_p^2 = 0.077$) for network centralities according to playing positions ($p = 0.001$; $\eta_p^2 = 0.079$). Significant interactions were observed between factors (successful or unsuccessful units * playing positions) for all network centralities (Pillai's trace = 0.021; $p = 0.001$; $\eta_p^2 = 0.007$), namely %IDC ($p = 0.001$; $\eta_p^2 = 0.011$), %ODC ($p = 0.008$; $\eta_p^2 = 0.007$), and %BC ($p = 0.001$; $\eta_p^2 = 0.014$).

Significant differences were found by the one-way ANOVA between playing positions for %IDC in unsuccessful ($p = 0.001$; $\eta^2 = 0.211$, *minimum effect*) and successful ($p = 0.001$; $\eta^2 = 0.129$, *minimum effect*) offensive units. Forwards presented the highest values of %IDC in both unsuccessful (13.84) and successful (10.17) offensive units. Significant differences were also observed between playing positions for %ODC in unsuccessful ($p = 0.001$; $\eta^2 = 0.148$, *minimum effect*) and

Table 1. Comparison of general network measures between successful and unsuccessful offensive units according to stage of competition

Stage of competition	Measure	Result of offense	Mean	*SD*	*p*	*d*
Round of all	Total links	Unsuccessful	18.20	12.71	0.166	0.328
		Successful	14.27	11.00		
	Network density	Unsuccessful	0.17	0.11	0.170	0.379
		Successful	0.13	0.10		
Round of 16	Total links	Unsuccessful	12.73	10.35	0.611	0.148
		Successful	14.18	9.07		
	Network density	Unsuccessful	0.12	0.09	0.583	0.117
		Successful	0.13	0.08		
Round of 8	Total links	Unsuccessful	18.22	14.16	0.033	0.631
		Successful	10.25	5.55		
	Network density	Unsuccessful	0.17	0.13	0.031	0.691
		Successful	0.09	0.05		
Semifinals	Total links	Unsuccessful	14.69	8.54	0.014	1.158
		Successful	5.63	6.02		
	Network density	Unsuccessful	0.13	0.08	0.014	1.114
		Successful	0.05	0.05		
Final	Total links	Unsuccessful	24.86	12.88	0.002	1.587
		Successful	6.50	8.62		
	Network density	Unsuccessful	0.23	0.12	0.002	1.578
		Successful	0.06	0.08		

SD – standard deviation

TABLE 2. Comparison of network centralities between successful and unsuccessful offensive units according to playing positions

	Playing position	%IDC		%ODC		%BC	
		Mean	*SD*	Mean	*SD*	Mean	*SD*
Unsuccessful	GK	0.58^{b,c,d,e,f}	1.54	2.16^{b,c,d,e,f}	3.21	0.4^{b,c,d,e,f}	1.81
	ED	8.34^{a,c,d,e,f}	6.86	10.69^{a,c,f}	7.64	7.08^{a,d}	9.22
	CD	5.74^{a,b,d,e,f}	6.73	6.05^{a,b,d,e,f}	5.98	5.35^{a,d}	8.27
	MF	11.24^{a,b,c,f}	8.29	11.55^{a,c,f}	7.92	9.41^{a,b,c,e,f}	10.65
	EMF	12.60^{a,b,c}	8.28	10.04^{a,c}	7.22	7.28^{a,d}	8.05
	FW	13.84^{a,b,c,d}	7.62	7.95^{a,b,d}	6.78	6.09^{a,d}	7.03
Successful	GK	0.42^{b,d,e,f}	2.01	1.05^{b,d,e,f}	3.54	0.11^{d,f}	0.59
	ED	3.62^{a,d,e,f}	6.28	5.88^{a,c}	8.59	1.89	4.86
	CD	1.86^{d,e,f}	4.64	2.24^{b,d,e}	5.13	0.85^{d}	3.15
	MF	6.15^{a,b,c,f}	8.56	6.17^{a,c}	7.99	2.49^{a,c}	5.42
	EMF	6.46^{a,b,c,f}	7.51	5.74^{a,c}	7.01	1.90	4.22
	FW	10.17^{a,b,c,d,e,f}	9.01	5.24^{a}	7.65	2.71^{a}	5.27

%IDC – indegree centrality, %ODC – outdegree centrality, %BC – betweenness centrality, SD – standard deviation, GK – goalkeeper, ED – external defender, CD – central defender, MF – midfielder, EMF – external midfielder, FW – forward

Significant difference from GK^{a}, ED^{b}, CD^{c}, MF^{d}, EMF^{e}, and FW^{f} for $p < 0.05$

successful (p = 0.001; η^2 = 0.062, *minimum effect*) units. Midfielders presented the highest values of %ODC in both unsuccessful (11.55) and successful (6.17) units. Finally, there were significant differences between playing positions for %BC in unsuccessful (p = 0.001; η^2 = 0.075, *minimum effect*) and successful (p = 0.001; η^2 = 0.031, *no effect*) offensive units. Midfielders presented the highest values of %BC in unsuccessful units (9.41) and forwards in successful units (2.17).

DISCUSSION

The study aimed to identify the main differences in the social interactions (connections and passes between players) in successful and unsuccessful offensive units. The presented data provide a better understanding of how national teams behave in offensive situations and indicate the passing patterns used by players to score a goal. This information might be useful for coaches both in the construction of offensive actions and in developing defensive strategies.

Regarding the general measures of SNA, literature has found higher total links in teams with better performance. Successful teams presented a higher number of connections amongst players [4] and these were positively associated with team performance [19]. Conversely, a higher number of total links (passes) was observed in this study in unsuccessful offensive units compared with successful ones in teams that achieved the last 3 stages of the competition (round of 8, semifinals, and the final). Differences in the results of the present study and previous research might be related to the performance indicators analysed. While previous studies used goals scored, overall shots, and shots on goal as the final performance indicators, or defined success of offense as plays that ended in a shot or those in which the team retained ball possession up to the finishing zone, this study analysed each offensive unit and defined success on the basis of a scored goal. Besides, Clemente et al. [4] found a weak positive correlation between total links or network density and goals scored and shots on goal. These divergent results might be bound with the type of offense analysed. While in this study only offenses that resulted in a shot were considered, Clemente et al. [4] analysed all passes made between teammates during a match. Therefore, it seems that the type of offense and the performance indicator chosen may influence the results of SNA properties. The more specific the analysis (i.e., only offensive units that ended in a shot and performance indicator as a goal scored), the clearer the results concerning the offensive actions performed to score a goal.

Similarly to total links, a higher density was found in unsuccessful offensive units in the last 3 stages of the competition. These results are in line with previous findings, indicating a negative effect of density on the success of offense [19]. One explanation for higher total links and density in unsuccessful offensive units may be that when teams perform a higher number of passes, they spend more time on offense, allowing the opponent to reorganize the defensive block and making it more difficult to score a goal. On the other hand, offensive units with less passes would lead to a shorter time for the opponent team to organize the defence and would increase the chance of success.

When referring to the centrality measures, central midfielders showed a higher value of %ODC both in successful and unsuccessful offenses, which supports the results of Clemente et al. [9]. This finding indicates that this tactical position plays an important role in the construction of offensive processes [9]. In addition, forwards presented the highest values of %IDC in successful and unsuccessful offensive units. One prior study also showed a higher demand on forwards in the defence-offense transition, suggesting that this playing position denoted the second most recruited player in this moment of the game [12]. These observations contradict the results obtained by Clemente et al. [9], who found the lowest value of %IDC (excluding goalkeepers) in forwards. However, Clemente et al. [9] analysed all situations that started with a successful pass to a teammate and that ended in the loss of ball possession. This probably included situations in which the ball did not get to the finalization zone (last third of the field) [12], where forwards are more recruited. It might have decreased their %IDC values. In this study and in the study by Malta and Travassos [12], only offensive units that ended in a shot or in the last third of the field were considered, which resulted in higher values of %IDC for forwards.

For %BC, midfielders presented the highest values in unsuccessful offensive units, which agrees with the findings of prior studies [9]. In turn, forwards presented the highest values of %BC in successful offensive units, to note that in the case of unsuccessful shots midfielders displayed significant differences between all other tactical positions and in the case of successful shots (goals) significant differences were found only when compared with goalkeepers.

One limitation of this study regards the lack of definition of where players were situated in the field in the moment of offense. The inherent dynamical characteristic of a game may have changed the players' place in the field, altering the spatial position that refers to each player. Therefore, in some offensive units, players from a specific position might have acted in areas that correspond to players from other positions. These offensive units were not discriminated in the analysis and might have had an impact on the SNA properties observed. Besides, the present findings must be considered with caution for professional teams, since national teams have a shorter practice time, which may influence their behaviours. Future studies should be conducted for professional soccer competitions to provide a better understanding of professional teams' offensive dynamics.

CONCLUSIONS

It can be concluded that the lowest level of density and total links can be associated with critical moments of goals in elite soccer. Total links and network density were significantly lower in successful than in unsuccessful offensive units, suggesting that offenses that resulted in a goal did not include the participation of all players and presented a lower number of passes (offenses within a shorter time). Besides, forwards are the most prominent players to receive the ball in both successful and unsuccessful offensive units and to intermediate the passing sequences during goal situations. This implies that forwards are common targets during the offensive process in soccer and their participation in offense does not determine success. Midfielders were the most central players to pass the ball and intermediate the passing sequences that resulted in missing goals. This indicates that playing styles based on ball circulation, mainly at the sides of the field, may be more likely to promote success in high level matches.

Disclosure statement

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Conflict of interest

Authors state no conflict of interest.

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