Title: Development of an innovative method for evaluating a network of collective defensive interactions in football.

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Abstract

Social network analysis (SNA) has been increasingly applied to performance analytics in team sports, seeking to better understand the dynamic properties of competitive interactions. Despite considerable potential to analyze individual (micro) and team (macro) behavioral patterns of play, there are important limitations that can undermine the potential applicability of SNA. One important limitation in existing research is the lack of network analyses of defensive interactions, curtailing understanding of the functionality and adaptability of teams during competitive performance. This study developed an innovative network method for assessing interactions between players in defensive phases of play in football. The networking method was evaluated using a small-sided and conditioned game (SSCG; GK+7v7+GK) of 20 minutes duration (two halves of 10 minutes each, interspersed by five minute intervals of active recovery). The method traced interactions between groups of three players (effective defensive triangulations) as network nodes, weighted according to the number of passes performed by the attacking players. Results showed how this social network analysis method may provide researchers, coaches, and performance analysts with relevant information regarding the functional properties of teams in the defensive phase of the game. For instance, coaches and performance analysts can evaluate the geometry of a team's defense, with players engaged in effective triangular-shaped positioning, that allowed them to provide defensive cover and defensive equilibrium, to protect the goal and recover ball possession.

Keywords: social network methodology, performance analysis, team defensive networks, effective defensive triangulations, Football, Soccer.

1 Introduction

Emerging approaches in team sports performance analysis have provided meaningful information regarding the topological structure exhibited by sports teams during competitive performance [1; 2]. Network science is one such approach and comprises an academic field, which investigates the functioning of complex collective systems such as computer, biological, and social networks, among others. Social network analysis utilises concepts and tools derived from graph theory to investigate social structures [3]. A social structure or collective (e.g., a sports team) can be framed as a network composed of individuals (e.g., players in teams), typically modelled as nodes or vertices, whose interactions are bounded by specific relational ties (e.g., a ball-passing network in a team game) [4].

In sports, social network analysis techniques provide insights into coordinated patterns of behaviour displayed by members of a team during competition, enhancing understanding of the topological structure of collaborative behaviours, investigating aspects like cohesiveness, roles, and hierarchies among players [3]. Additionally, and more importantly, network analysis bridges the gap between the *micro* (e.g., dyads, triads, and small groups) and *macro* (e.g., the whole structure) levels of analysis [5]. Therefore, social network analysis supports identification of local and global patterns of team behaviour, examining system (team) dynamics.

Despite the benefits associated with the applicability of social networks to team sports performance analysis, there are important limitations to current methodological understanding that need to be addressed. One such limitation relates to the absence of a network analysis on team interactions when defending in team games like football [6]. Indeed, previous social network studies have provided knowledge regarding interactional patterns displayed by team players during the process of information exchange in attacking phases of play (e.g., ball-passing networks) [7-13]. Other studies have used social network metrics, along with other performance indicators, to identify the most important players in football attacking plays [14]. These, and other research limitations, can be resolved through use of network science and tracking data to study collaborative activity in systems during defensive phases of play [15-18].

The combination of network analysis with tracking data provides a rich understanding of how team dynamics emerge and evolve over time (see, for example, [19], for a review on the application of tracking methods to assess tactical variables in team sports). In addition, network science allows analysis of tracking data with patterns of play against different opponents/conditions/spaces/others. On the other hand, the vast majority of data-driven performance indicators are based on football log data (i.e., Wyscout, Chiavari, Genoa, Italy, and Stats, London, UK). Such reports are mainly focused only on ball-related events during play, consequently it is not possible to evaluate whether a defender prevented a penetrative pass from being completed by positioning themselves close to an immediate opponent. There is a need to also understand the interactional patterns of players in defending teams.

This lack of information regarding the network of team defensive interactions is very important to consider, because in competitive performance, a crucial source of information constraining the perceptions and actions of collective agents (e.g., players in sports teams), is provided by the actions of other interacting agents (e.g., opponents) [20].

Based on network theory, competitive team games, like football, can be conceived as an emergent competitive relationship between collective systems conceptualised as two cooperative and interdependent complex networks, striving to surpass each other's performance effectiveness and efficiency through numerous skill-based interactions. From the standpoint of Network B, the interactions of members of Network A are deemed as external input, having an impact on the global topology and local dynamics of Network B, and vice-versa [9].

During competitive performance, the two competing networks have mutually exclusive goals, displaying complex antagonistic behaviours. On one side of the spectrum, the team in possession of the ball frequently seeks to create space by stretching and expanding space on field, through increasing values of interpersonal distances between players, aiming to create goal-scoring opportunities. On the other side of the spectrum, when defending, teams close down space by contracting and reducing space between players, aiming to recover ball-possession or to prevent the opposing team from accessing passing lanes to create scoring opportunities. Such collective system tactical behaviours emerge from the assembly of interpersonal synergies established between teammates, which can be captured, for example, through the analysis of the effective area of play of both competing teams.

This effective playing space, also called surface area, has been defined as the smallest polygonal area delineated by all the peripheral players participating in a game [21]. Several studies have utilised information from this, and other collective system metrics, to enhance understanding of tactical behaviours concerning the expansion and/or contraction movements displayed by players within and between teams, in competitive environments [22-26]. In this regard, Clemente, Couceiro, and Martins [27] have used previous information on the application of this tactical metric to develop a new method for computing effective areas of play. They calculated effective playing areas for both attacking and defending teams, taking into consideration time spent with and without possession of the ball. This process allowed them to analyse the effective offensive/defensive triangulations established between players during goal-directed performance.

We propose that this novel method of analysing the effective playing area can be used as a possible basis for developing a methodological approach for assessing a network of defensive interactions in sports teams. Indeed, Yamamoto and Yokoyama [9] have emphasised that game momentum can be depicted by the number of “offensive triangular shapes” (triangular passing in groups of three players) achieved in attacking sequences of play. In this study, local and global dynamics inherent to team sports were investigated based on a ball-passing network that sustained collective system behaviours. Insights of Yamamoto and Yokoyama [9] have raised pertinent and interesting questions, such as: can team interactions when defending be modelled by a network of effective defensive triangulations formed by interactions of three players? In addition, why is measurement of triangulations important? We argue that a geometric shape (triangle) is commonly manifested by players during competitive performance in many of the major team games, including football, and may facilitate the execution of tactical principles of play in defensive sub-phases of play, including providing cover and equilibrium. If players maintain diagonal lines with respect to each other and the position of the ball, while defending, they may facilitate the accomplishment of key principles of defensive cover and balance, enabling individual and collective defensive organisation to be more effective [28]. Defensive cover can be provided by player(s) supporting the teammate closest to the ball carrier, aiming to serve as a covering barrier in case the attacker with the ball manages to dribble past that defender. Likewise, the principle of balance can be provided by defending player(s) able to close gaps between different teammates, covering any attacking passing lines, as well as limiting space and movement of free players (between and behind attackers). Nevertheless, it is important to mention that this network method comprises a first attempt to measure such relations, and thus future research needs to be done to evaluate individual and colletive defensive organization underlying the achievement of effective defensive cover and balance during competitive performance.

In the proposed network approach, the organization of a defending team can be considered to emerge from the interactions between its cooperating players, creating defensive networks. These collective sub-systems are weighted, based on the number of successful interactions with other defending teammates. These defensive interactions are *spatially embedded*, considering the Euclidean position of the players, and *time evolving*, by considering the number and shape of the effective triangular shapes formed through interactions of three defenders over time. It is important to emphasise that this novel network approach is able to represent and measure the spatial interaction between defenders and the spatial areas of triangulations between defenders according to the interactions performed. Regardless, there have been no attempts to develop a methodological approach for assessing a network of team defensive interactions in team sports, like football. The rationale basis that supports this methodological approach in this study regards groups of three players (defensive triangulations) as the vertices of the defensive network, weighted according to the passes performed by the players of the attacking team. On the other hand, it is important to note that, in this study, we applied our proposed approach in a Gk+7v7+Gk SSCG that is representative, although less complex (due to decreased number of players and space), of the 11-a-side formal match. We provide detailed information regarding the methodological protocols that were used, reporting practical applications and possible avenues for future research.

2 Methods

2.1 Sample

The proposed method was assessed in a single 8-a-side (GK+7x7+GK) small-sided and conditioned game (SSCG) format, consisting of two 10-minute halves interspersed by an active recovery interval of five minutes. The game was implemented at the beginning of football class to avoid possible fatigue effects on performance and was preceded by a warm-up of approximately 10 minutes, comprising drills with a ball followed by sprinting activities and stretching. The convenience sample was composed of 16 players (20.7±1.3 years) recruited from the Sports Faculty of the University of Porto, enrolled in football classes as part of their Sports Science degree curricula. Only the outfield players were considered for the analysis. Goalkeepers participated in the study but were excluded from the analysis because of their restricted positioning on field, compared to other players. The coach assigned participants to one of two, technically-equivalent teams composed of eight players.

The objective of teams in the SSCG was to score as many goals as possible while preventing the opposing team from scoring. The SSCG was played outdoors on an artificial turf field. The length and width dimensions of the playing area were reduced, relative to official football field dimensions to 63.6 x 41.3 m, due to the number of players involved in the SSCG [29]. Moreover, the teacher did not provide any type of encouragement or feedback to the players, before and during periods of data collection, because it could have affected levels of practice intensity in individual participants. During the recovery period, participants were allowed to recover actively at will. Players were informed about the procedures of the study and signed an informed consent form. The local Ethics Committee approved the study.

2.2 Procedures

To capture team interactions on field, a GoPro (San Mateo, California, USA) Rollei Ac415 FHD WiFi (a fixed digital camera) was used, encompassing the following characteristics: (i) resolution: FullHD; (ii) processing capacity of 50 Hz (50 frames per second); (iii) maximum lens aperture: F=2.4; (iv) sensor type: CMOS; (v) capture angle: 140º. The GoPro was placed on a higher level above the pitch (approximately 6 m high) to ensure an optimal viewing angle (allowing views of the entire field) during the game.

In addition, global positioning tracking devices (GPS) were utilised for capturing on-field players' displacements. All outfield players (a total of 14 players) carried an unobtrusive global positioning tracking device (Qstarz, model: BT-Q1000Ex, Team PSA Sport, Taipei, Taiwan) that recorded their longitudinal and latitudinal positional coordinates, for each individual positional data (2D) sample, at a sampling frequency rate of 10 Hz (10 frames per second). The reliability of such GPS devices has been confirmed in previous studies [30-31]. The performance area was calibrated in the anterior axis using four GPS devices stationed in each corner of the pitch for approximately four minutes. The absolute coordinates of each corner were calculated as the median of the recorded time series, yielding measurements that were robust to the typical fluctuations of GPS signals. These defined locations were utilised to establish the Cartesian coordinate systems for each pitch, with the origin placed at the pitch center. Furthermore, longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates by applying the Haversine formula [32].

We adapted the method proposed by Clemente et al., [27] to calculate the adjacency matrices for both teams' A and B defensive networks. We used positioning tracking devices (GPS) to collect the 2D positional coordinates of players on the field. Furthermore, video analysis was used to annotate, for each second of the first and second halves of play if the team with possession of the ball (attacking team) performed a pass or not. Data processing and analysis involved dedicated Matlab R2016b (MathWorks, Natick, Massachusetts, USA) routines for transforming positional coordinates of players and pitch, to synchronise data from video and GPS, as well as to calculate adjacency matrices and graphically illustrate the attacking and defending effective areas of play for both teams.

2.2.1 Effective area of play

Clemente et al., [27] proposed a different calculation of the surface area of play, denoted as effective area of play, which considers the effective triangular shapes formed in each team. To calculate the effective area of play, there is a need to create a polygon on the planar dimension in which at least three points are necessary (i.e., triangle). Accordingly, three players need to be considered to build triangular shapes as the combinations of *N* players, in which *N* represents the total number of players within a team.

For that purpose, an algorithm was developed comprising the subsequent following steps:

1. Calculation of the surface area for each team after the work of Frencken and colleagues [22,23].

2. Computation of the surface area of both teams with all the non-overlapping triangular shapes formed by groups of three players in each team. Here, the major condition was to generate the triangular shapes with smaller perimeters.
3. Calculation of the effective area of play formed by the triangular shapes that did not overlap the surface area of the opposing team.
4. Calculation of the effective area, derived from the formation of defensive triangular shapes established by a team, that intercepted the surface area of the opposing team.
5. Calculation of the triangular shapes formed by attacking players in a team that were not intercepted by the effective defensive triangular shapes of the opposing team.

These measures were used to quantify the interactions between defending players, as opposed to the traditional surface area measure, because it encompasses both offensive and defensive tactical principles. These measures give relevance to the latter by focusing on the concentration (position of defenders away from the ball who occupy vital spaces to protect the scoring area) and the defensive unit (positioning of defenders to reduce the effective play-space of opponents) [27].

2.2.2 Network of team defensive interactions

The criterion we adopted to develop a network of team defensive interactions was based on the formation of effective defensive triangulations by team players. As mentioned before, the interactions between a set of three players (in a triangle) constitutes a necessary requisite for creating a polygon that represents the entire surface area occupied by the defending team, with special reference to the effective area of play. Importantly, it also serves as the basis for the calculation of the connections established among defending players. Such connections permit analysing different levels of team cooperation, moving from single (individual) and subsequently more complex dyadic, and triadic levels of analysis, towards the whole team structure.

Each player represents a node of the network, weighted according to the interactions accomplished with other defending teammates, captured through the defensive triangle, only when the attacking team passed the ball**.** In other words, the weighted triangle (interactions of three defensive players) varied according to local and global dynamics of the team in possession of the ball. Basically, the network of team defensive interactions is expressed by the number of players' effective defensive connections established with other teammates that enabled the formation of effective triangulations (triangle perimeter ≤ 36 m), through analysis of the effective area of play. Such effective defensive triangular shapes were captured in response to a ball-passing action developed by the attacking team in possession of the ball.

The ball-passing action of the attacking team was measured using a combination of video and GPS analyses. For the purpose of synchronising the sampling time rate between video analysis (50 Hz) and GPS (10 Hz) positional data analysis, the following steps were completed: 1) downsampling (process of reducing the sampling rate of a signal) of 10 Hz GPS original data to 1 Hz in Matlab (sampling rate of one second); and 2), analysis and registration of passing sequences through video analysis, for both Team A and Team B for every second of the game. This procedure was needed to ensure the same sampling rate between both video and GPS data and to identify the starting point of both datasets by matching/synchronising the beginning of the game. Moreover, additional information regarding the passes completed by both teams for each second of the game and for both halves was also included in the CSV file containing the GPS coordinates. This information was coded using a simple binary identifier (0 - no pass; 1 - pass) for pass identification. Basically, the positional coordinates (x, y) of all the outfield players and the information for pass identification compose the dataset (CSV file).

To facilitate this synchronization procedure, a Matlab graphical interface was developed, enabling us to view the video frame-by-frame (*i.e.*, at every second), alongside the GPS coordinate data imported directly from CSV, thus allowing us to recognise the location and movements of each player (represented by a point) on-field, as exemplified in Figure 1. This provided the visual information necessary to identify the starting point (beginning of the game) and match it with the GPS data. Only the rows of the CSV file that contained the positional coordinates (x, y) of players, coded as "1" (successful pass), were considered by the Matlab script to assess the network of interactions established by the defending team.

INSERT FIGURE 1

2.2.3 Replicability of data analysis

Regarding the replicability of this method, such an approach requires a fixed camera, GPS devices for all the players, a synchronisation process (e.g., the use of scripts elaborated in Matlab or OCTAVE software) and a manual or automatised annotation process (for passes identification).

3 Results and Discussion

The results of the adjacency matrices for Team A and Team B defensive networks are shown in both Table 1 and Table 2. To best summarize the information in both Tables, as an example, we have only focused our attention on the interactions involving Player 1 (for Team A and Team B), because the subsequent interpretations for the remaining players (Player 2-7) are identical, only the number of interactions achieved by each pair vary.

INSERT TABLE 1

Thus, effective defensive connections (EDC) and total effective defensive connections (TEDC) achieved by players of Team A are represented in Table 1. For instance, Player 1 established 1,322, 748, 1,384, 1,006, 477 and 663 EDC with Player 2, 3, 4, 5, 6 and 7 respectively, comprising a total of 5,600 TEDC performed throughout the whole period of the game. The player with most TEDC accomplished was Player 4 (TEDC = 5,636). The player with whom Player 4 established more EDC was Player 1 (1,384).

Like Table 1, Table 2 represents the EDC and TEDC displayed by players of Team B.

INSERT TABLE 2

Player 1 established 1,357, 855, 1,098, 828, 293 and 275 EDC with Player 2, 3, 4, 5, 6 and 7 respectively, encompassing a total of 4706 TEDC. The player with most TEDC accomplished was Player 2 (TEDC = 5,006). The player with whom Player 2 established more EDC was Player 3 (1,442).

Beyond the adjacency matrices for both teams' defensive networks, we also obtained graphic imagery (a total of 1,200 frames depicting the 20 minutes of play, 20 min of play = 1,200 seconds) illustrating the offensive and defensive spatial areas of triangulations performed by players. Figure 2 depicts the first second of the game and demonstrates the disposition on field of both attacking and defending players (assessed by positional coordinates) when a pass was performed by a player from Team 1. Each image shows the surface area of both attacking (Team 1) and defending team (Team 2) with non-overlapping (Figure 2) and overlapping (Figure 3) triangular shapes. The surface area of both teams' is calculated by adding the existing triangulations of the effective area of play, allowing us to obtain a value that informs the total coverage area of the polygon formed by the attacking and defending teammates [25].

INSERT FIGURE 2

The high dimensionality presented in the adjacency matrices of both Team A and Team B defensive networks is related to the number of possible defensive connections that a given player can establish with his teammates, during each second of the game. For instance, the player assigned with a black circle (Figure 3) establishes five defensive connections (order of numbers was set arbitrarily) with his teammates, resulting in the formation of four effective defensive triangulations in the ninth second of the game.

INSERT FIGURE 3

As mentioned before, this methodological approach conducts network analyses on formation of defensive triangulations to assess player interactions on the field. The formation of triangulations between defenders may best provide defensive cover and balance to facilitate the tactical principles of play. Indeed, when the defending players attain effective triangular shapes the probability of the attacking players to perform a pass towards that particular zone of the field or even to penetrate that space through dribbling actions can be very low given the accurate position of the defending players (perimeter of the triangle ≤36m) the three-player interpersonal interaction allows them to comply with two major specific principles of the game, namely defensive cover, and balance. Regardless, there is a need for future research to ascertain the relation between the perimeter of triangular shapes and effectiveness of ball-recoveries.

However, the distance of players providing defensive cover for their nearest teammates is extremely difficult to ascertain because it is dependent on a variety of conditions, for example: (i) the area of the field where the game situation occurs; (ii) technical-tactical capacity of the attacking player(s); (iii) velocity of the moving defender(s); (iv) state of the playing area surface and weather conditions, amongst other reasons [33,34]. Regardless, insights from previous research by Dooley and Titz [35] allowed us to establish a maximum perimeter of 36 m (approximately 12 m between each defensive player) for defining an effective defensive triangle. Consequently, those triangular shapes formed by the defending teammates that exceeded the distance of 36 m would be nullified by the triangular shapes formed by the attacking team, based on the assumption that it would be more difficult for the defensive players to intercept the ball [27] or to provide defensive cover for their nearest teammates with that spatial dimension. However, according to the same investigators, the effective area of play *per se* does not warrant a need for defensive cover, rather it allows us to analyse the potential for the defending players to support their nearest teammates based on their proximity on field.

We only counted the EDC value established between players in triangular shapes that were considered effective (perimeter ≤ 36 m for the defensive triangular shapes that intercepted the offensive triangular shapes). It is important to mention that, when there is no overlap between the playing areas of teams, all defensive triangulations are considered effective. Only when there is an overlap of playing areas of competing teams, can those triangular shapes that exhibit perimeters ≤ 36 m be considered effective. Essentially, the results provide the frequency counts of successful interactions accomplished by each player with other defending teammates. In other words, both defensive network matrices of Team A and Team B reflect the accumulated sum of all the passes made by the opposing team while the players kept the defensive network connected.

It is important to mention that this study protocol did not account for any contextual factors such as, for example, quality of the opponent, score-line. Arguably, such factors will influence the emergence of effective defensive triangular shapes between team players. Regardless, the main aim of this study was to ascertain whether the combination of the network approach, along with tracking data, allowed the capture of effective team defensive triangulations during competitive performance. On the other hand, we are aware that the triangular shapes' perimeter reference used in this study is set for 11-a-side matches. However, this specificity does not compromise the proposed approach because the triangle's perimeters may vary according to a multitude of interacting performance constraints, which can be studied in future studies.

Summarising, the analysis of the network of team defensive interactions was based on a ball-passing network performed by the attacking team in each second of the game. Graphical representations for each frame of the game (frames containing a pass) allowed us to evaluate the effective defensive triangular shapes (shaped by three player interactions – nodes of the defensive network) whose perimeter value was ≤ 36 m. The effective defensive triangular shapes were weighted according to the number of passes performed by the attacking team.

4 Conclusions and Practical Applications

This study sought to develop an innovative methodological approach to evaluate a network of interactions between defending players in football. Notwithstanding, care must be taken when interpreting the results found in this study. In fact, the proposed methodological approach was implemented in a Gk+7v7+Gk condition, therefore, despite representing the 11-a-side formal match at a reduced complexity level, further research is needed to generalize the results to the full game format.

Nonetheless, this methodological advance may constitute a first step to overcome one of the main limitations encountered when social network studies are applied to the study of sports performance, providing relevant information regarding the adaptability and functionality exhibited by teams in competitive and practice environments. In addition, the applicability of this methodological approach may benefit future social network studies by expanding knowledge beyond that of collective networks during offensive interactional patterns, enhancing understanding of the "rapport of forces" [36] manifested by competing teams. It may also constitute the basis for future extrapolations to performance analysis in other team sports.

Finally, network analysis, enhanced by understanding of a network of team defensive interactions, may provide coaches, practitioners and performance analysts with deeper insights concerning functional patterns of tactical behaviours in individuals and teams for different phases of competition. The efficacy of football tactics can be best understood in terms of creating (attacking phase) and/or closing down (defending phase) space as well as controlling space. Coaches and performance analysts can evaluate the geometry of teams in a defensive phase, with players achieving geometrically accurate positioning, based on establishment of effective triangular shapes that allow them to adequately provide defensive cover and defensive equilibrium and, ultimately, to protect their goal area and recover the ball.

5 Future Research

A key next step is to develop this methodological approach by including in the analysis, for example, the dribbling actions performed by attacking players. This analysis only provided information on the network of team defensive interactions in response to a passing move from the opposition. Another important step to contemplate in future studies is to elaborate network metrics that allow investigations of the topological properties displayed in coordinated defensive interactions developed by players during performance. Indeed, this is an important step to further understand the dynamics of the network of collective defensive interactions. Beyond that, the inclusion of the positional coordinates of the ball, may be extremely useful to simultaneously analyse the interactive behaviours of both offensive and defensive networks displayed by competing teams. Furthermore, one can also develop a unique network, which contains information regarding the complexity manifested by two opposing networks in competing teams. Finally, it would be of great interest to ascertain the most dominant spaces used for each triangular shapes and to verify if there is any correlational relationship between each triangular shapes over time.

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7 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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