Measuring spatial interaction behavior in team sports using superimposed Voronoi diagrams

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Abstract

In team sports, the spatial distribution of players on the field is determined by the interaction behavior established at both player and team levels. The distribution patterns observed during a game emerge from specific technical and tactical methods adopted by the teams, and from individual, environmental and task constraints that influence players’ behaviour. By understanding how specific patterns of spatial interaction are formed, one can characterize the behavior of the respective teams and players. Thus, in the present work we suggest a novel spatial method for describing teams’ spatial interaction behaviour, which results from superimposing the Voronoi diagrams of two competing teams. We considered theoretical patterns of spatial distribution in a well-defined scenario (5 vs 4+ GK played in a field of 20×20m) in order to generate reference values of the variables derived from the superimposed Voronoi diagrams (SVD). These variables were tested in a formal application to empirical data collected from 19 Futsal trials with identical playing settings. Results suggest that it is possible to identify a number of characteristics that can be used to describe players’ spatial behavior at different levels, namely the defensive methods adopted by the players.

Key words: spatial interaction, Voronoi diagrams, Futsal, spatial measures
1. Introduction

Team sports are considered dynamic systems of interaction, where players from both teams continuously change, adapt, adjust and coordinate their position and actions in order to win the game (Davids, Araújo and Shuttleworth, 2005; Passos et al., 2009). Pre-determined tactical and technical methods, along with individual, environmental and task constraints (Newel, 1986) regulate players’ spatial behaviour and are responsible for a continuous emergence of patterns of intra-and inter-team interaction. Research on this subject should therefore assume a holistic character considering a time and space continuous approach, which is accomplished when defining variables capable of describing the collective behavior of a team (Schölhorn, 2003, McGarry, 2009).

When considering the space dimension, players’ trajectories during a game are a relevant source of information but they only provide a measure of team behavior when considered simultaneously. Following this reasoning, spatial team variables, such as the convex hull (Frencken et al., 2011), the stretch index (Bourbousson, Sève, and McGarry, 2010a) and simple measurements derived from the average position (centroid) of the whole team (Frencken and Lemmink, 2008; Bourbousson, Sève, and McGarry, 2010b; Frencken et al., 2011), have been considered to describe the behavior of a team. These variables are illustrated in Figure 1a), b) and c), respectively.

The mentioned variables became popular for describing the spatial behavior of each team across the duration of a game (or task). Typically, the area of the geometric shape (Figure 1a) and b)) is calculated for each team or, in case of using the centroid (Figure 1c)), its distance or angle to the aimed target (e.g. goal) is considered as a measure of individual team behavior.

![Variables for describing team spatial organization of two opponent teams](image)

Figure 1. Variables for describing team spatial organization of two opponent teams (players of each team are represented by black dots and triangles, respectively, grey players on the top and bottom of the field are the goalkeepers) – (a) convex hull, (b) horizontal and vertical stretch and (c) centroid position (red dots).
For the analysis of these data series, researchers consider the use of entropy measures to quantify and compare the complexity of the spatial behavior of the teams (Passos et al., 2009; Fonseca et al., 2012a; Sampaio and Maças, 2012) and, for assessing teams’ coordination, a relative phase analysis is considered (Bourbousson, Sève, and McGarry, 2010a; Travassos et al., 2011). While these approaches are a step forward towards the understanding of players’ behaviour in team sports, some limitations can be identified, as illustrated in Figure 2.

Figure 2. The same spatial configuration of two teams GK+5 vs 5+GK (players of each team are represented by black dots and triangles, respectively, grey players on the top and bottom of the field are the goalkeepers) measured using the area of the respective convex hull (shaded areas) in three very different scenarios (a, b and c).

Figure 2 shows the same spatial configuration of two teams in three very different scenarios of team interaction, which would present no differences if, for example, the area of the convex hull of each team is considered. This limitation can be found in some variables currently used to describe spatial behavior in invasive team sports as they are calculated for each team ignoring the spatial distribution of the opponent team and the dimension of the field. Given that the spatial organization of one team is much influenced by the spatial organization of its opponent, it seems reasonable to consider the position of all players in the field, as well as its dimension, to define variables that describe teams’ spatial arrangement. Thus, some authors have suggested measures of spatial organization based on a geometric partition of space called Voronoi diagram (see Okabe et al., 2000), in which parts of the field, the Voronoi cells (VCells), are associated to each of the players. Figure 3 shows an example of a Voronoi diagram generated for a set of 10 points in a limited square area.
The application of this spatial tessellation in team sports has been welcomed as the points can represent the position of the players and the associated VCells can be interpreted as the dominant region of each player within the limits of the playing area (field). Not surprisingly, such an approach has been considered in a variety of settings, namely, electronic soccer games (Kim, 2004), robotic soccer (Law, 2005), on-field hockey games (Fujimura and Sugihara, 2005), on-field soccer games (Taki, Hasegawa, and Fukumura, 1996) and on-field Futsal (Fonseca et al., 2012b). Although some principles of the game are fully captured in these studies (e.g., the idea that the attacking team has to free-up space and the defensive team has to tie-up space), it is still unknown how relationships established at a player level relate to this. Hence, we suggest a novel spatial method for describing inter-team spatial interaction patterns of behavior in invasive team sports, which also allows characterizing the type of play of defending teams. Results from an application of this approach in Futsal task situations are presented.

2. Method

The spatial method suggested here, illustrated in Figure 4, results from superimposing the Voronoi diagrams (VD) of the two teams competing (VD of team A - black, over VD of team B - white), hereafter named Superimposed Voronoi Diagram (SVD).

Given this graphical construction, we defined two measures of spatial interaction: the maximum percentage of overlapped area (Max%OA) and percentage of free area (%FA). The former (Max%OA) is calculated for each player of a team and it represents the maximum percentage of that player’s VCell covered by the cell of an opponent (note that the VCell of a players can be covered by more than one opponent’s VCell); as for the latter (%FA), it is a measure that summarizes the degree of similarity between the overlapped diagrams, and is calculated by subtracting from the play area the sum of the Max%OA calculated for players of a team. A representation of these measures is presented in Figure 5.
Figure 4. Construction of the superimposed Voronoi diagram (at bottom) from considering, separately the Voronoi diagrams for team A (black dots) and team B (white dots).

Figure 5. Measures from the superimposed Voronoi diagram (SVD): (a) shaded grey areas are the maximum Overlapped Area for each player of the team represented with black dots; (b) the sum of the shaded black area is the Free Area.

The fitting of the two diagrams, VD of team A and VD of team B, is clearly dependent on the spatial distribution of the players from both teams, and a perfect fit would only occur if players of a team could be in the exact same position of the players from the other team, which in a sports context would make no sense (note that in this case the Max%OA would be equal to 100% to all players and hence the %FA would be null). A more likely scenario in invasive team sports is having players exclusively paired at each instant of the game, i.e., matched one-to-one as in a man-to-man defensive method, in which case the two VD would be similar, but not identical.

An alternative scenario is having all players randomly distributed in the field at each instant of the game, i.e., players would only be paired by chance, and one would expect a weak match of the two diagrams. Although this is scenario is not intuitively associated with a specific situation of the game, spatial randomness is often considered as a reference model for spatial patterns assessment. Deviations from spatial randomness will point towards other spatial models, resulting from an aggregation (attraction) or segregation (repulsion) of individuals.
Having described these two possibilities, we recognize the importance of understanding how these two measures of interaction (%FA and Max%OA) differ in these two scenarios. Thus, simulated spatial patterns of exclusive pairing and random interaction were performed to derive the properties of the SVD. The simulation settings matched those in the empirical data considered for application purposes (5 vs 4+ GK players in a limited region of 20×20m). Nevertheless, it is supported that this can be adjusted to other scenarios.

Random interaction: 1000 SVDs were generated for random interaction, i.e., all players except GK are randomly allocated in the field, the GK is fixed at location (10,18) – example of one simulated pattern is shown in Figure 6a.

Exclusive pairing: Given the numerical advantage for the attack in the present setting (5 vs 4+GK), each defender, except GK, was paired with one of the 4 attackers closer to the center of the goal. The GK remains fixed at location (10,18). Thus, 1000 SVDs were generated for exclusive pairing at different maximum distances between pairs, from 0.5 to 7 meters with increments of 0.5 meters – example of one simulated pattern is shown in Figure 6b.

![Figure 6](image.png)

Figure 6. Example of a generated SV in a situation where (a) players from both teams (grey and black dots) are randomly distributed in the field and (b) defender players, grey dots, are exclusively paired with the attacker players, black dots, that are closer to the goal. The GK (red dot) is in both cases fixed at position (10, 18). The arrow indicates the direction of the attack.

2.1. Inter-Team interaction assessment
For measuring inter-team interaction the %FA was considered. In case of random interaction, this measure is, on average, equal to 36 ± 7.2% and the corresponding 95% confidence interval is (0.22, 0.50)%. As for the exclusive pairing patterns, given that in this case the %FA calculated for each of the 14 distances was not normally distributed, we have computed the 95% confidence envelopes. These are compared with the values expected in the presence of random interaction in Figure 7.
As expected, when opponent dyads are tightly paired, i.e., for very small pairing distances, the %FA is smaller than what is expected by chance (random interaction). As this distance increases, the pairing becomes weaker and the %FA increases towards the values observed under complete randomness. In fact, results suggest that for the specific settings considered in this study, 5 vs 4+GK played in a field of 20×20m, it is only possible to identify exclusive pairing at a team level when the distance between all pairs is below two meters (dotted vertical line in Figure 7).

2.2. Opponent interaction assessment
For assessing spatial interaction at a player level we consider the Max%OA for each player. As illustrated in Figure 8, we found that this variable is associated with the number of opponents within the player’s Voronoi area – the more the number of opponents the smaller the value of Max%OA of the attacker (p<0.001).
Hence, this variable can be used to characterize the interaction of one player with the opponents, in particular, the density of opponents in his vicinity. According to the simulated data results presented in Figure 8, values of the Max%OA below 0.4 indicate that the attacker is in a situation of clear numerical disadvantage (dotted horizontal line).

3. Results

The described methodology was applied to empirical data collected from 19 Futsal attack trials, 5 vs 4+GK played in a limited region of 20×20m. Data results are shown for four randomly selected trials. The observed patterns of behavior, assessed by means of the %FA (see Figure 9), indicate more towards low levels of exclusive dyadic interaction (%FA values inside the interval (0.22, 0.50)%), which was expected as defense players were playing in a zone defense fashion due to their numerical disadvantage.

Figure 9. Observed %FA (percentage of Free Area) in a sample of 4 trials (solid black line) and the 95% confidence interval for absence of interaction (dashed grey lines). Values within the dashed lines (0.22, 0.50) indicate low levels of exclusive dyadic interaction.

In addition, for testing for the opponent interaction, and according to what was described above, it was considered the Max%OA for each attacker. Figure 10 shows the Max%OA for each of the five attackers across the duration each selected trials. This variable allows identifying the attacker(s) that penetrate the defensive structure.
Indeed, the periods of the task highlighted in each of the sampled trials showed in Figure 10 are related with two kinds of situations: 1) when the corresponding attacker enters the defensive structure with the intention of receiving a pass from the ball carrier or 2) when the attacker is the ball carrier and is positioned very close to the goal. In both situations, players from the defensive team tend to protect the goal and gain ball possession, which leads to a pressure towards these attackers and hence lower values of their Max%OA.

4. Discussion

This paper presents a novel approach for studying spatial interaction in invasive team sports. The method here described is based on the Voronoi diagrams (VD), which are a geometric construction previously suggested to represent, for each player and/or team, the corresponding dominant region (Kim, 2004; Law, 2005; Fujimura and Sugihara, 2005; Taki, Hasegawa, and Fukumura, 1996; Fonseca et al., 2012b). The superimposition of the VD of both teams here suggested allow the definition of variables, other than the dominant region, which can be considered to describe the spatial interaction behavior at an individual and collective level. These variables may be useful for characterize the tactical behavior of the teams and, in particular to identify the defensive method adopted throughout a game. As these variables are calculated based on the teams’ overlapped area, they are more informative regarding the spatial interaction of the players in comparison with others, such as the area of the convex hull.
(Frencken et al., 2011), the stretch index (Bourbousson, Sève, and McGarry, 2010a) and simple measurements derived from the average position (centroid) of a team (Frencken and Lemmink, 2008; Bourbousson, Sève, and McGarry, 2010b; Frencken et al., 2011), which are calculated for each team separately, ignoring the interaction context.

Results from a formal application of this novel approach to empirical data collected in task situations in Futsal suggest that it is possible to identify a number of characteristics that can be used to describe players’ and teams’ spatial behavior. In one hand, it is possible to describe the interaction between the two teams by comparing the spatial pattern formed by the respective players, which is much dependent on the interaction established among pairs of opponents, i.e., if players are exclusively paired, as they would be in a man-to-man defensive method, the % FA will be below the reference values calculated for situations when such interaction is not imposed (random interaction). On the other hand, and by means of a different variable extracted from the same superimposed graphical construction, Max%OA, it is possible to describe, across the duration of the game (or task), the type of interaction established between each attacker and his opponents, in particular to distinguish between different types of numerical relation, for example, situations of more or less pressure, which corresponds to having many or few opponents in his vicinity, respectively.

Note that in this work, the areas defined by the VD, which are then superimposed, are solely based on players’ position and limits of the playing area. Other factors likely to influence the size of these areas such as ball position, distance from ball, distance from goal, direction and speed of the displacement as well as players’ skills were not considered, but we intend to add these in future work on this area. Regardless these limitations, the reference values for each of the variables here described can be generated to different scenarios, varying the number of players and field dimensions, which allow a broad application of this methodology for studying and comparing interaction behavior in a variety of invasive team sports.

5. References

Davids et al. (2005)


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