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Measuring Collective Behaviour in Football Teams: Inspecting the impact of each half of the match on ball possession

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Abstract
The aim of this study was to inspect the influence of each half of match and the ball possession status on the players' spatio-temporal relationships. Three official matches of a professional football team were analysed. From the players' locations were collected the team's wcentroid, wstretch index, surface area and effective area of play at 9218 play instants. The results suggested that the values of teams' dispersion and average position on the field decreases during the 2nd half of the match. In sum, this study showed that the half of match and the ball possession status influenced players' spatio-temporal relationships, in a way that significantly contributes to the collective understanding of football teams.

Key-words: Football, collective behaviour, metrics, match analysis.

1. Introduction

Match analysis on football teams has been well studied based on the notational and kinematical analysis in the past years (Vilar, et al., 2012). Recently many findings were published highlighting the relevance of several performance indicators contributing to the improvement of individual and collective behaviour during playtime (Hughes & Franks, 2004; Carling, et al., 2005). For instance, the difference in ball possession in the 1st and 2nd half of the football game is considered to be one of the main bases for performance improvement (Lago & Martín, 2007; Bangsbo, et al., 2006). The fatigue component is generally associated with the two halves of a game (Mohr et al., 2005). Ball possession can be associated with both defensive and offensive moments, and it

also determines the number of individual and collective actions (Lago & Martín, 2007). Nevertheless, notational and kinematic analysis are not the only solutions to identifying the properties of a football team (Duarte, et al., 2012). In the past few yearsit became possible to identify a spatio-temporal dimension of football teams (Vilar, et al., 2012)based on the bidimensional positions of the players (provided by tracking systems). In this paper the spatio-temporal analyses are depicted as collective metrics.
Some basic collective metrics have been proposed in order to inspect the intra- and inter-team relationships (Bourbousson, et al., 2010; Frencken, et al., 2011; Moura, et al., 2013). These metrics use a player's Cartesian coordinates on the field to compute a set of relationship parameters (Clemente, et al., 2013). One of the metrics used the most is the team's centroid (Bartlett, et al., 2012). This metric is very similar to the concept of centre of gravity, *i.e.*, the centroid position is calculated by examining the x and y coordinates of all players (Clemente, et al., 2013). Several studies suggest that due to the instability between the centroid of both teams it is possible to analyse some goals scored in open play (Frencken, et al., 2011). Another collective metric concept is the stretch index (Bourbousson, et al., 2010). This metric is based on the standard deviation concept, where the centroid is the "average" value. Based on regular expansion-contraction relationship between the football teams, the higher dispersion values are naturally associated with the offensive moments (Bartlett, et al., 2012). Furthermore, an inverse relationship is expected between both teams' stretch indexes (Clemente, et al., 2013).

The metric proposed in order to inspect the team's configurations of play is the surface area (Frencken, et al., 2011; Moura, et al., 2013). This metric detects all possible triangulations performed by the team players (Moura, et al., 2013). The combined area of all triangles is then computed based on these triangulations, thus providing the entirearea covered by the team (Frencken & Lemmink, 2008). This metric enables the identification of the possible actions for each team by inspecting the geometric configuration performed by all players (Gréhaigne, et al., 2011). A similar concept is exhibited in the effective area of play metric (Clemente, et al., 2013). It detects all possible triangulations but considers only some of them. The effective area of play metric is based on the effective defensive triangulations and only considers those that are not overlapped by the opposite team or the defensive triangulations with a small and balanced perimeter (Clemente, et al., 2013). This concept enables the detection of regions with higher and lower effectiveness of teammates' spatial coordination.

Despite the introduction of many technological advances in the past few years, a team's analysis based on tactical inspection or collective metrics (*e.g.*, spatio-temporal dimension) is still underdeveloped in comparison to the notational analysis (Vilar, et al., 2012). Due to the increase in efforts needed to develop collective metrics, some parameters (*e.g.*, half of the match, ball possession) have not been included in the collective changes analysis so far. Therefore, the aim of this study is to analyse the influence of the two halves of match and ball possession status on collective behaviour. Thus, several dependent variables would be analysed during three games of one team: centroid value, stretch index, surface area and effective area of play. It is expected that higher values of the centroid, stretch index, surface area and effective area of play will occur during the moments with ball possession, *i.e.*, offensive moments. It is also expected that the lower values of the centroid, stretch index, surface area and effective area of play will occur during the 2nd half of the match.

2. Methods

2.1. Sample

Three home matches ofa professional team were analysed. At each match the final score was different, *i.e.*, winning, losing or drawing. Thus, every match was considered by each final score. From those 3 matches were collected 9218 instants. All of the collected data complies to the APA ethical standards for the treatment of human or animal subjects.

2.2. Data Collecting

Teams' actions were captured using a digital camera (*GoPro Hero* with 1280 × 960 resolution), with capacity to process images at 30 Hz (*i.e.*, 30 frames per second). The camera was placed on an elevated surface above the ground in a way that would capture the whole field. The field dimensions were 104×68 meters. After recording the football match, the physical space was calibrated using direct linear transformation (*DLT*), which amendsthe position of the elements (*i.e.*, players and ball) in pixels to the metric space (Abdel-Aziz & Karara, 1971).

Tracking of players was accomplished after calibrationwhichreturned the position of the players and the ball over time in Cartesian coordinates (*see* Figure 1). The whole process associated with this approach(*i.e.,* detection and identification of players' trajectories, space transformation and metrics computation), was performed using the high-level calculation tool *MatLab*.

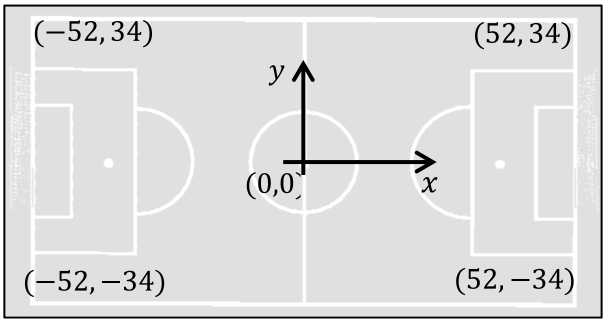

Figure 1. Football referential field

As a matter of efficiency, only playtimewas considered, excluding all moments in which the ball was not in the field (*i.e.*, ball out of bounds). Since the herein proposed methodology inherits some computational complexity, each second will correspond to an analysed instant of each player and the ball.

Computing the collective behaviour

Five collective metrics were computed for the match analysis: *i*) weighted centroid; *ii*) weighted stretch index; *iii*) surface area; and *iv*) effective area of play. The following section presents a descriptive summary of each metric.

i) Weighted Centroid (wC):

The centroid value is a computation of the geometric centre of a team. This metric is considered for its usefulness in computing the in-phase relations between two opposing teams in longitudinal and lateral directions (Bourbousson, et al., 2010). Moreover, it is also used to analyse the equilibrium point of a team, considering the distribution among its players. The centroid calculation has been introduced without considering the position of the ball and the player's proximity to it. Nevertheless, the proximity to the ball is an important factor that should be considered. Therefore, the Clemente et al (2013) approach was used, considering that the proximity of the players to the ball would assign different weights to the centroid position. The relevance of each player to the team's centroid, *i.e.*, w_i weight, was based on the Euclidean distance between each player and the ball as follows:

$$w_i = 1 - \frac{\sqrt{(x_i - x_b)^2 + (y_i - y_b)^2}}{d_{max}} \tag{1}$$

wherein (x_b, y_b) corresponds to the position of the ball and d_{max} is the Euclidean distance of the farthest player to the ball at each iteration (Clemente, et al., 2013).

In order to improve the statistical analysis, inverted players displacement was introduced so as to overcome the changes after each half of the match. Thus, team A would always attack towards positive coordinate values and the opponent team would always attack toward negative coordinate values (*see* Figure 1).

ii) Weighted Stretch Index (wSI):

The stretch index value represents the expansion or contraction of area covered by the team in longitudinal and lateral directions (Bourbousson, et al., 2010). The stretch index is measured based on the centroid position, thus it is the sum of each player's dispersion onboth axes. Similarly to the team's centroid, a weighted team's stretch index metric may then be calculated as (Clemente, et al., 2013):

$$wSI = \frac{\sum_{i=1}^{N} w_i d_i}{\sum_{i=1}^{N} w_i} \tag{2}$$

wherein d_i is the Euclidean distance between player i and the team's centroid, *i.e.*,

$$d_i = \sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2} \tag{3}$$

Within this context, the stretch index can be obtained by computing the mean of the distance between each player and the centroid of the team.

iii) Surface Area (SA):

The surface area is based on the calculation of the entire area covered and the sum of triangulations emerging from the match (Frencken, et al., 2011). Therefore, the sum of emerging triangulations is the value of all possible triangular combinations of *N* players, in which *N* is the total number of players within a team (Clemente, et al., 2013). In the particular case of football, a maximum of eleven players (for each team) could be on the field at the same time Hence, all possible combinations of three out of eleven players, is a total of 165 cumulatively formed triangles (Clemente, et al., 2013). Consequently, the sum and area of the triangulations are computed at every instant.

iv) Effective Area of Play (EAP):

The effective area of play metric is based on the surface area. Nevertheless, it is one more parameter related to ball possession. This parameter is used to analyse the overlapping occurring between opposite triangulations. When a defensive triangulation has an area of more than 36 meters, the offensive triangulation will be considered instead of the defensive one (Clemente, et al., 2013). This is necessary since the great amount of open space between the defensive players decreases the difficulty for the offensive players to overcome the opposition (Dooley & Titz, 2011).

3. Results

The applied descriptive statistics during the moments without ball possession (Table 1) shows that the x-*w*centroid presents higher values on the first half.This phenomenon may suggest that the defensive phase is performed closer to their penalty area. Althoughduring the first half the team's y-*w*centroid is closer to the central midfield than in the second half,during the whole gamethe team depicts a tendency to ensure that its y-*w*centroid remains on the left side of the field.

Table 1. Descriptive statistics of dependent variables in the moments without ball possession.

Ball Possession			Mean	Std. Deviation	Minimum	Maximum
Without Ball Possession	x-*w*centroid [m]	1st Half	-8.247	13.349	-46.233	32.364
		2nd Half	-7.462	13.922	-50.888	31.810
		Total	-7.851	13.645	-50.888	32.364
	y-*w*centroid [m]	1st Half	0.420	9.470	-24.123	24.486
		2nd Half	0.674	10.634	-28.939	24.755
		Total	0.548	10.074	-28.939	24.755
	*w*Stretch Index [m]	1st Half	15.339	2.867	3.227	25.529
		2nd Half	14.953	3.565	4.771	31.128
		Total	15.144	3.243	3.227	31.128
	Surface Area [m^2]	1st Half	1369.689	349.381	142.705	2659.604
		2nd Half	1277.547	468.929	92.451	3432.162
		Total	1323.247	416.484	92.451	3432.162
	Effective Area of Play [m^2]	1st Half	349.327	210.364	0.000	1166.673
		2nd Half	369.614	284.472	0.000	2812.880
		Total	359.552	250.650	0.000	2812.880

The dispersion metrics (*i.e.*, stretch index and surface area) applied on the team exhibited a decreasing tendency during the second half of the match. Nevertheless, it was possible to identify an increasing evidence by benefiting from the effective area of play, with a total effective area of 369.614 m^2in the second half and 349.327 m^2 in the first half.

In Table 2, it is possible to observe the results of all dependent variables during the ball possession moments. Similar to the moments in which the team does not possess the ball, the x-*w*centroid presents higher values during the first half, thus suggesting that the team remainscloser to their own goal. Nevertheless, the y-*w*centroid reveals a change of flank between the first and second halves. During the first half, the team remains closer to right side of the field (average value of -2.132 m) while in the second half, the team tends to left side of the field (average value of 2.006 m).

Table 2. Descriptive statistics of dependent variables in the moments with ball possession.

Ball Possession			Mean	Std. Deviation	Minimum	Maximum
With Ball Possession	x-*w*centroid [m]	1st Half	-2.888	13.748	-45.305	41.079
		2nd Half	-0.225	13.583	-50.913	40.411
		Total	-1.560	13.729	-50.913	41.079
	y-*w*centroid [m]	1st Half	-2.132	9.563	-25.611	22.967
		2nd Half	2.006	10.675	-29.871	23.661
		Total	-0.068	10.341	-29.871	23.661
	*w*Stretch Index [m]	1st Half	18.018	3.057	6.438	25.878
		2nd Half	17.064	4.168	5.854	35.193
		Total	17.542	3.684	5.854	35.193
	Surface Area [m^2]	1st Half	1831.319	452.003	260.162	3082.400
		2nd Half	1638.088	644.066	151.683	3789.971
		Total	1734.948	564.419	151.683	3789.971
	Effective Area of Play [m^2]	1st Half	1334.243	485.381	0.000	3048.152
		2nd Half	1140.255	641.618	0.000	3275.304
		Total	1237.494	576.848	0.000	3275.304

Both *w*stretch index and surface area shows a higher tendency to spread the team during the offensive moments occurred in the first half. This may be observed considering the results of the first half *w*stretch index (18.018 m) and surface area (1831.319 m^2) when compared with the results from the second half, namely 17.064 m for the*w*stretch index and 1638.088 $m^2$for the surface area.

The overall results (*i.e.*, considering all possession moments) are presented on Table 3. As previously addressed, the team has a tendency to approximate the x-*w*centroid to its own goal during the first half. Moreover, during the first half, the team tends to remain in right side of the field (-0.900 m of y-*w*centroid) while during the second half it remains in the left side (1.356 m of y-*w*centroid).

Table 3. Descriptive statistics of dependent variables in all moments

Total			Mean	Std. Deviation	Minimum	Maximum
Total	x-*w*centroid [m]	1st Half	-5.476	13.817	-46.233	41.079
		2nd Half	-3.758	14.216	-50.913	40.411
		Total	-4.615	14.044	-50.913	41.079
	y-*w*centroid [m]	1st Half	-0.900	9.602	-25.611	24.486
		2nd Half	1.356	10.675	-29.871	24.755
		Total	0.231	10.216	-29.871	24.755
	*w*Stretch Index [m]	1st Half	16.724	3.255	3.227	25.878
		2nd Half	16.033	4.026	4.771	35.193
		Total	16.378	3.678	3.227	35.193
	Surface Area [m^2]	1st Half	1608.387	466.670	142.705	3082.400
		2nd Half	1462.070	593.359	92.451	3789.971
		Total	1535.038	538.911	92.451	3789.971
	Effective Area of Play [m^2]	1st Half	858.604	620.843	0.000	3048.152
		2nd Half	764.023	631.323	0.000	3275.304
		Total	811.191	627.868	0.000	3275.304

Both *w*stretch index and surface area reveal a decreasing tendency on the second half. Similar results can be observed for the effective area of play, where the team presents a mean result of 858.604 m during the first half and 764.023 m during the second half.

4. Discussion

The spatio-temporal relationship in football teams is one of the main bases to explain the relationship between football players (Duarte, et al., 2012). From the individual perspective to the collective organization, most works emphasize on players' synchronization (Bourbousson, et al., 2010; Moura, et al., 2013). As part of the spatio-temporal relationship, collective metrics can provide some more insights toward an improved understanding of players and teams' dynamics (Clemente, et al., 2013). As this specific information cannot be retrieved using regular notational information, collective metrics recently started to play a major role in sports' analysis (Vilar, et al., 2012). Despite these developments, explaining some changes in the collective performance over time still remains a challenge. Therefore, the aim of this study was to inspect how the ball possession status and the half of match can influence the collective organization by benefiting from collective metrics.

The different performance during the halves of the match has been mainly associated with the fatigue (Carling, et al., 2005). Usually, studies have demonstrated that a set of indicators, such as sprinting, running and distance covered, are lower in the 2^{nd} half of match (Bangsbo, 1994). Therefore, this may suggest a performance inhibition (Mohr, et al., 2005). Nevertheless, the question on how the spatio-temporal relationships between players can be affected by this fatigue was still uncovered. This study presented statistical differences between the 1^{st} half and 2^{nd} half of matches. In all dependent analysed variables, a decreasing tendency was found in the 2^{nd} half. The *w*centroid position in the longitudinal axis decreased for all 2ndhalf matches. This can be associated with a specific adjustment of the team on trying to reduce their general exposure to offensive moments. In fact, the team may still present a similar amount of offensive situations but with fewer players or with more balance. This can be associated with the more active recovery periods in the 2nd match by each player on trying to manage their own fatigue. Nevertheless, it is unanimous that players in all team, regardless of their position in the field, experienced a significant decline in high-intensity running closer to the end of match (Bangsbo, et al., 2006). Therefore, the number of players per each attack unit can be lower, thus reducing the *w*centroid position in the longitudinal axis.

Furthermore, it was possible to observe a decreasing tendency in the stretch index, surface area and effective area of play during the 2nd half of match. Once again, the fatigue can explain the willingness to take some offensive and defensive collective behaviour (Mohr, et al., 2005). With higher physical capacity, it is possible to explore the whole width and length of the field, while trying to unbalance the opponent team. Moreover, the intensity and frequency of exploring actions can be higher in the 1st half because the fatigue is not as evident (Bangsbo, et al., 2006). As a consequence, if the offensive actions are more intense and frequent, then the defensive actions will be higher in number too (Dooley & Titz, 2011). A higher offensive expansion will attract a higher expansion of the defensive team, despite their contraction playing principle (Gréhaigne, et al., 2011). Moreover, the higher physical capability during the 1st half allows players to coordinate their actions with higher proximity. This proximity promotes a higher effectiveness in the triangulations, subsequently increasing the team’s effective area of play (Dooley & Titz, 2011). In spite of this,the fatigue cannot be the only phenomenon yielding to these collective oscillations over match (Duarte, et al., 2012). Indicators such as the score, team’s strategy or ball possession can also determine the predisposition to perform some collective behaviours (Lago & Martín, 2007; Taylor, et al., 2005). For that particular reason, the influence over the ball possession was also studied.

Regarding the ball possession, it was possible to observe an increasing tendency to expand players’ displacement on the field along offensive moments. This finding can be associated with the stretch index, surface area and effective area of play. In point of fact, in the offensive phase (*i.e.*, with ball possession) the team explores the width and length of the field and tries to unbalance the focus and unit of the opponent team (Clemente, et al., 2013). In other words, the outcome is in line with the width and length offensive playing principle (Costa, et al., 2010). Conversely, without ball possession one can observe a decreasing tendency on the total area covered and the dispersion. This behaviour is associated with one of the main goals during the defensive phase, *i.e.*, to ensure the team’s balance and reduce the inter-sectorial spaces (Moura, et al., 2013).A certain proximity between teammates is necessary to reduce the inter-sectorial spaces (Vilar, et al., 2012). This proximity helps to ensure an inter-coverage between each other, *i.e.*, each player tries to maintain an optimal distance with his teammates to be covered by him and, at the same time, to cover himself (Dooley & Titz, 2011). By reducing the inter-sectorial spaces, the opponent team will need to struggle so as to penetrate and unbalance the defensive formation. Therefore, these findings are in line with the expansion-contraction relationship (Moura, et al., 2013). Beside theteam’s dispersion, the collective behaviour on defensive and offensive states can also be observed in the longitudinal *w*centroid. In fact, the team's *w*centroid gets closer to its own goal. This is a normal behaviour in defensive phase. Nevertheless, the *w*centroid is weighted based on how closer players are to the ball, thus suggesting a high level of participation of all players in the defensive phase.

About the effective area of play between both moments (*i.e.*, with and without ball possession) it can be discussed based on the optimal inter-relationship between teammates in both moments. Even reducing the space during the defensive moments, their proximity ensures the effective triangulations, thus reducing the opportunity to build the offensive triangulations. Hence, there is a kind of equilibrium between offensive and defensive moments, wherein the defensive triangulations try to reduce the offensive triangulations. Nevertheless, it is normal to obtain a higher effective area of play while with ball possessions in the offensive triangulations can be generated with larger inter-player distances (Figure 2).

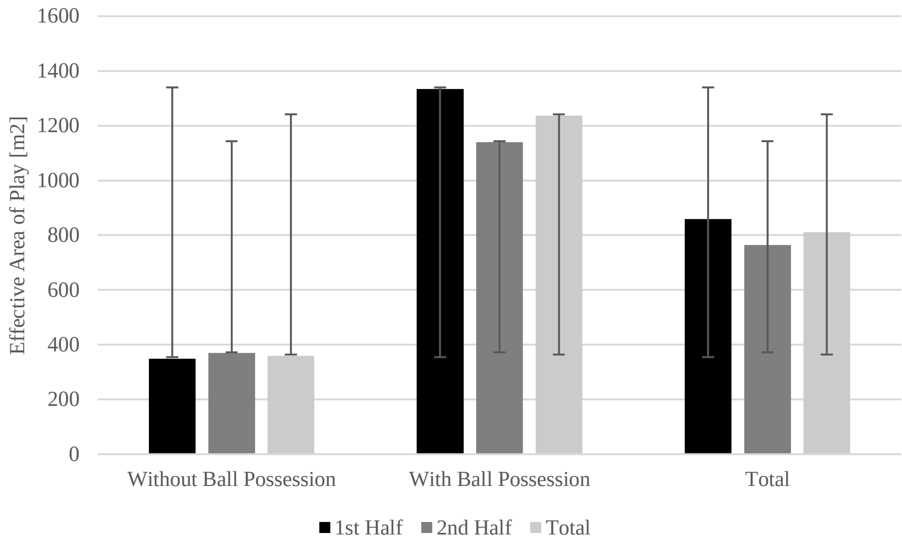

Figure 2. Effective area of play during the match

The interaction between both factors (*i.e.*, half of match and ball possession) was also analysed. By crossing these variables it was possible to observe a higher average of longitudinal *w*centroid on the 2nd half with ball possession. On the other hand, the lower average of longitudinal *w*centroid was found in the 1st half without ball possession. These findings can be associated with each team's strategy. In fact, there is a tendency to explore the counter-attack on the 2nd half in order to explore the opponent defenders fatigue, thus resulting in an increase in the*w*centroid position. The reduced position in the 1st half without ball possession may suggest a conservative approach on protecting their own goal, reducing the *w*centroid position.

It was also found that the higher dispersions measured using the *w*stretch index and surface area are associated with offensive moments in the 1st half. On the other hand, a smaller dispersion value was found in the 2nd half without ball possession. In fact, this makes sense since players' physical capability is higher during the first half of the game it is easier to unbalance the opponent's defensive equilibrium (Bartlett, et al., 2012).

Thus, the dispersion from the width to the length is bigger. This expansion behaviour also attracts the defenders, thus increasing at the same time the defensive dispersion while trying to maintain an optimal concentration and proximity (Costa, et al., 2010). Thus, if the offensive expansion is higher in the 1st half, it is possible that its reduction during the 2nd half can increase the defensive contraction, thus reducing the defensive dispersion. It was also discovered that the effective area of play value is higher in the 1st half with ball possession and lower in the 2nd half without ball possession. The higher expansion observed using the dispersion metrics can justify the higher area of play in offensive moments (Clemente, et al., 2013). On the other hand, the higher effective area of play without ball possession in the 1st half can be associated with the higher physical capability to ensure an optimal proximity between teammates.

However, a lot of research remains to be done on the factors that influence collective behaviour. This study was influenced by some limitations since it is not possible to measure the fatigue levels precisely. Nevertheless, similarly to other studies performed on official matches, fatigue levels were inferred by the reduced individual kinematic performance from the 1st to the 2nd half of the game (Carling, et al., 2005). Thus, a decreasing tendency in the values measured by collective metrics was observed in this study. Other examples of the aforementioned limitations include the score of the match and each team's strategies (Lago & Martín, 2007). Nevertheless, the aim of this study was to analyse the collective behaviour as a spatio-temporal relationship, trying to justify some changes over the course of the match in relation to several parameters. Naturally, it is impossible to consider all variables justifying collective behaviour, thus this study only focuses on two main factors used in notational analysis.

In summary, this study performed an analysis on the collective behaviour during a game of football, based on several match variables in order to explain the inter-relationship oscillation. The novelty presented in this study is the analysis performance based on collective metrics, thus bringing forth new possible future approaches. For instance, the notational, kinematic and collective metrics could be integrated at the same time in order to explain a given reality. Furthermore, new independent variables could be introduced such as the classification, season's moment or even the specific playing strategies. Nevertheless, the practical contribution of this study is to present a new match analysis approach based on collective metrics, as well as to analyse the influence of match variables in order to explain existing changes in players' inter-relationships. Using this information makes it possible to improve the understanding of the teams' play style and to possibly detect specific properties. Utilizing this knowledge in the daily trainings makes it possible to overcome some non-desired collective behaviour changes.

5. Conclusion

The specific spatio-temporal relationships between football players are some of the main factors for the understanding of the football game as a whole. Nevertheless, few studies have been performed in order to analyse the factors influencing those relationships so far. Therefore, the aim of this study was to inspect how the half of match and ball possession status can influence the collective organization. The results suggested that the values of teams' dispersion and average position on the field decreases during the 2nd half of the match. The possible cause of this is the increase of fatigue which in turns leads to a decrease in players' ability to secure an optimal spatio-temporal relationship between their teammates at any moment of the match. Furthermore, an expansion-contraction relationship between the offensive and defensive moments was detected. Thus, the results suggested a higher team's dispersion during the 1st half and the moments with ball possession. This higher dispersion value can be associated with the width and length offensive principles of play, as well as with the higher physical capability of the players to displace in the field. The lower dispersion values are associated with the concentration of defensive principles of play, as well as with the active recovery management.

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