Capturing meso-level synchronisation tendencies in elite football teams: A novel method for analysing collective organisation in performance

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Capturing meso-level synchronisation tendencies in elite football teams: A novel method for analysing collective organisation in performance

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Abstract:

This study explores emergent synchronisation tendencies in elite football teams, emphasizing how players coordinate their collective actions in sub-phases of play to achieve performance goals under various competitive constraints. Drawing on ecological dynamics, the study highlights the player-environment relationship, analysing how ecological variables, such as field position, goal targets, and locations of teammates and opponents, shape collective decision-making. A novel method, using a newly developed coordinate system for capturing meso-level synchronisation tendencies is introduced, defined by values of angle and distance of subgroups of players (simplices) to the goal. This approach is designed to capture the continuous adaptive needs of homeostatic regulation in performance, successfully observing and reporting synchronisation tendencies between players that emerge at the meso-level scale. Results demonstrated greater system sensitivity in detecting synchronisation tendencies between players, compared to traditional coordination analysis methods. The key performance variables, angle and distance to goal, are critical constraints on players' synchronized behaviors during competitive performance. This novel method for observing and reporting synchronisation tendencies can provide team sports coaches with crucial information to effectively structure and monitor player transactions during performance and training sessions.

Keywords: Football teams; Meso-level synchronisation; Distance and Angle to goal; Collective homeostasis, Player transactions

1. Introduction

Synchronisation tendencies among players in team sports have drawn significant attention, driven by growing interest in understanding how cooperation and coordination among team members emerge in performance (e.g., Carrilho et al.[1], Corrêa et al.[2], Folgado et al.[3], Ribeiro et al.[4]). Investigating synchronisation tendencies in elite football is crucial, showing how players coordinate their actions to achieve common goals while adapting to informational constraints.

Grounded in the theory of ecological dynamics, the decisions and actions of individual players are continually shaped by surrounding information sources, such as field markings, the rules of the game, and the locations of teammates and opponents on the field [5]. Information is used to regulate actions, particularly those related to available affordances (i.e., opportunities for action[6]), which appear and disappear in the performance environment. For example, pitch areas, goal location, and the co-positioning of teammates and opponents – cooperative and oppositional relationships captured by simplices[7] – are critical ecological variables in competitive football. These constraints shape players' behaviours and influence their synchronisation tendencies, ultimately affecting the team's collective dynamics. Among these ecological variables, the players' distance and angle relative to the goal have been identified as crucial factors influencing tactical decision-making and coordination patterns (e.g., Romero Clavijo et al.[8], Vilar et al.[9]).

Synergetic behaviours in teams emerge at the micro (e.g., dyadic player relationships such as 1 vs. 1), meso (group dynamics such as 3 vs. 2), and macro (team interactions) levels. These levels align with the hierarchical organization of open systems[10], where each level represents a distinct layer of complexity that is interconnected, yet governed by specific dynamics and constraints. In this context, the meso-level encompasses functional groupings of players—comprising both teammates and opponents—who are temporarily coupled by shared task demands or available affordances in performance (e.g., pressing opportunities, spatial occupation near the ball, collective coverage of passing options). These groupings are not static, but rather dynamically assembled as the game evolves. The mesolevel has been recognized as a key ecological level for understanding emergent synergy-formation processes, particularly in solving competitive challenges[4]. However, despite its importance, meso-level analysis has received limited research attention[11], reinforcing the need to bridge this gap in the literature. A deeper understanding of this intermediate level than is currently available is essential for linking individual player interactions to the collective organisation of the team.

During competitive performance, specific subgroups of players emerge dynamically in offensive and defensive sub-phases of play. These transient yet functionally important interactions serve as a bridge between the micro and macro levels, as players engage with their closest teammates to generate consistent patterns of performance behaviours[4]. Understanding these meso-level dynamics is essential for capturing how local player interactions contribute to team synergies[12].

In this regard, sports teams have been modelled using the concept of *collective homeostasis*[13]. This theoretical model consists of four fundamental components: i) players; ii) set point; iii) identifier; and iv) adapter. In the context of football, players are conceived as self-regulating agents who perceive and respond to dynamic informational sources in the environment, such as ball location, teammate and opponent co-positioning, and spatial opportunities for action. The set point represents the team's functional goal or reference state during a given phase of play—for example, maintaining possession, progressing toward the opposition goal, or constraining space defensively. The identifier refers to the tactical or perceptual processes through which players detect deviations from that intended state (e.g., perceiving information on a shift in numerical balance or the emergence of a defensive threat). The adapter reflects the team's capacity to self-organise and generate adaptive responses in real-time to restore or maintain alignment with the set point—such as reconfiguring defensive shape following a transition. The present study focuses specifically on the players and the adapter components, which reflect the team's ability to generate adaptive responses through self-organising processes. The model suggests that sports teams possess a self-regulatory capacity, enabling them to adaptively respond to information emerging from various competitive constraints, thereby reinforcing the emergence of synergetic behaviours across different levels of complexity (micro-meso-macro levels)[13].

From this perspective, meso-scale behaviours exemplify collective homeostasis in action, offering insights into how adaptive behaviours at a smaller scale contribute to the structural stability of the team[13, 14]. One way to access such coordination dynamics is through the analysis of synchronisation tendencies, which capture how players move in relation to one another and to the team as a whole[15]. Traditionally, the synchronisation tendencies of longitudinal and lateral displacement measures on the field have been assessed using separate measures based on team-team (e.g., Duarte et al.[15]) and player-team (e.g., Duarte et al.[15]). However, in a football game, players perform a variety of multidirectional displacements[16], not limited to longitudinal and lateral displacements, and their positioning in relation to both goals can influence decision-making[9].

Seeking to investigate synergy formation in football teams, Ribeiro et al.[4] introduced a novel method for assessing meso-level synchronisation tendencies within and between subgroups of players – i.e., referred to as simplices, or relational structures (e.g., 2 vs. 1) that emerge during competition. To capture meso-level synchronisation tendencies more accurately during football performance, the present study aimed to develop and test a novel method of analysis, using a newly developed coordinate system, defined by the performance variables of angle and distance of players within relational structures (i.e., simplices) to each goal.

In this study, synchronisation refers to the emergent, spatiotemporal alignment of players' actions within dynamically-forming relational structures (simplices) that arise from evolving task constraints. These transient interactions reflect how players temporally coordinate their positioning and movements in relation to teammates, opponents, and key affordances (e.g., space, goal, passing lanes)[4]. Synchronisation tendencies, thus, are indicators of functional alignment within a given context, capturing how subsets of players fluidly adapt their behaviours in pursuit of collective goals. Rather than defining synergy, synchronisation reflects the temporal coordination that underpins it—offering insight into the evolving (self)organisation of interactions that support team functioning. By analysing synchronisation through analysis of ecologically meaningful variables—specifically, from data on players' distance and angle relative to the goal—we aim to capture more accurately how these transient interactions are organised around key affordances (opportunities or solicitations for action[6]) in football. This approach offers a functionally-grounded perspective on collective system adaptation that extends beyond the provisions of traditional displacement metrics.

Accordingly, this study aims to: i) analyse synchronisation tendencies using new performance variables, specifically players' distance and angle relative to the goal; ii) compare synchronisation tendencies using traditional longitudinal and lateral displacement measures with those based on distance and angle to the goal, assessing potential differences in their informational value; and iii), verify whether synchronisation tendencies vary across different field zones, providing insights into how contextual constraints shape team coordination patterns.

2 Materials and methods

2.1 Materials

This work presents a case study, and the data were obtained through convenience sampling, meaning it was selected based on accessibility and availability. The positional raw data (2D) of 28 male professional football players from two teams (11 starting players and three substitutes per team), recorded during a professional league match, was provided by STATS. The validity and reliability of this tracking system have been quantified to verify the capture process and data accuracy[17, 18]. These data were obtained, at a rate of 1 Hz, on a playing field with an effective playing area of 68-m wide by 105-m long, from a multiple-camera match analysis system recording the players' movements during performance, with the cameras located at the top of the stadium. The data provided by STATS was synchronized with additional annotation data referring to the ball possession (team A, none, team B). The annotation was performed by a single observer on two separate occasions, with an intra-observer kappa coefficient greater than 0.80, which is generally interpreted as indicating strong agreement[19].

2.2 Data pre-processing

The positional data was pre-processed with an interpolation method for imputation of missing positional data. The number of imputed positional values was below 0.5% of the total frames.

2.3 Ecological variables: simplices and pitch location

The informational constraints resulting from the relative locations of teammates and opponents are characterized at a meso-level (between global metrics such as teams' convex hulls and dyadic relations between pairs of players) using sets named simplices. All the elements in a simplice, its players and goals, are linked by an hyperedge. Figure

1 illustrates the set of simplices identified in a particular match frame. Here, simplice σ_n is composed of players 8, 11, and 12 from the blue (A) team and 27 from the red (B) team, i.e., $\sigma_n = \{a_8, a_{11}, a_{12}, b_{27}\}$.

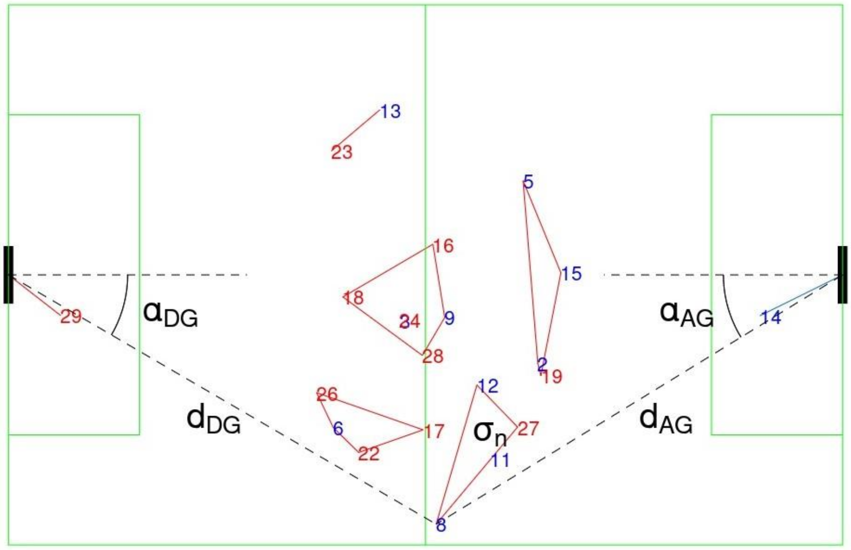

Figure 1. Schematic representation of simplices (player sets connected by hyperedges, e.g., $\sigma_n = \{a_8, a_{11}, a_{12}, b_{27}\}$) and analysis variables (distance and angle to attacked, d_{AG} and α_{AG}, defended goals, d_{DG} and α_{DG} represented for player a_8). The direction of the goal being attacked is from left to right.

Hyperedges are set with proximity-based criteria, such that each player is always in the same simplice as its closest player or goal (the algorithm for computing the simplices is presented in supplementary materials).

In this study, we focus on how the synchronisation of the analysis variables among the players of each simplice depends on its location on the field. For this purpose, as illustrated in Figure 2, the field is divided into six longitudinal and four lateral field zones (defensive (DEF1-DEF2), midfield (MID1-MID2), and attacking (ATT2-ATT1) thirds) and the simplices' location is defined by the zone containing its centre of mass.

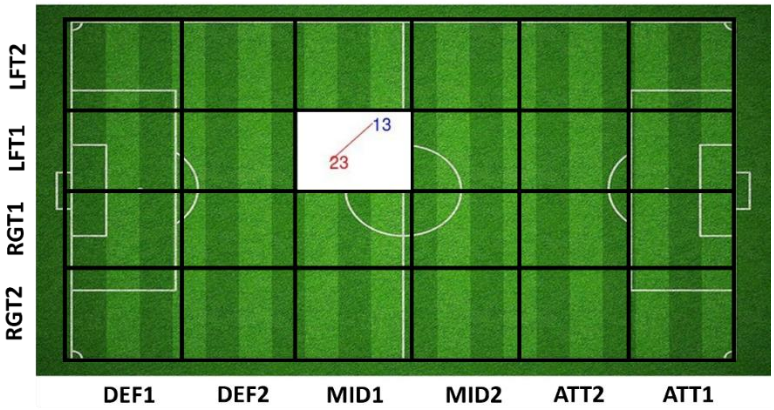

Figure 2. Field segmentation in six longitudinal (DEF – defensive third; MID – midfield third; ATT - attacking third) and four lateral zones (RGT – right side; LFT – left side). Location of simplices is defined by their centre of mass on the 6 x 4 cell grid, e.g., (MID1, LFT1) for the example simplice.

2.4. Variables under analysis and their synchronisation

In this paper, the analysis variables are defined as the value of the distance and the angle to the attacked and defended goals ($d_{AG}, a_{AG}, d_{DG}, a_{DG}$) from the perspective of players in each simplice (as illustrated in Figure 1).

In the current study, the level of synchronisation can, thus, be computed using an extension to the process applied in the modelling of Ribeiro et al.[4] where the co-positioning of different *subgroups* (simplices) of players can be considered[20, 21], i.e., the level of synchronization ρ for simplice σ_n in frame k, regarding analysis variable v, $v \in \{d_{AG}, a_{AG}, d_{DG}, a_{DG}, d_{Long}, d_{Lat}\}$, is given by $\rho_{\sigma_n,k,v} = \frac{1}{s_k}\left\|\sum_{p\in\sigma_n} \exp\left(i(\theta_{p,v}(k) - \bar{\theta}_{p,v}(k))\right)\right\|$, where s_k is the size of simplice σ_n, $\theta_{p,v}(k)$ is the phase of analysis variable v for player p at frame k and $\bar{\theta}_{p,v}(k)$ its mean over all the elements given by $\bar{\theta}_{p,v}(k) = \tan^{-1}\left(\frac{1}{s_k}\sum_{p\in\sigma_n} \exp\left(i\theta_{p,v}(k)\right)\right)$.

The phase, $\theta_{p,v}(k)$, of the analysis variable v for player p at frame k is computed based on methods used by Varlet and Richardson [22], i.e., $\theta_{p,v}(k) = \tan^{-1}\left(\frac{v'_p(k)}{v_p(k)}\right)$, where $v_p(k)$ is the value of the analysis variable v for player p at frame k and $v'_p(k)$ its period normalised time derivative. For each of the four analysis variables ($d_{AG}, a_{AG}, d_{DG}, a_{DG}$), the within simplice synchronisation value is computed at each frame and associated to the possession status and field location as represented in Table 1. For comparison purposes, the synchronisation value for the longitudinal and lateral displacements, d_{Long} and d_{Lat}, is also computed.

Table 1

Sample of the synchronisation values computed from the positional data.

Frame, k	**Team**	**ID, n**	**Location**		**Synchronisation value, $\rho_{\sigma_{n,k},v}$**					
			cx	**cy**	d_{AG}	a_{AG}	d_{DG}	a_{DG}	d_{Long}	d_{Lat}
783	A	3847	ATT2	LFT1	.845	.905	.736	.880	.769	.823
783	A	3446	DEF2	RGT1	.758	.645	.822	.888	.901	.899

Note: **Frame** – sample number, **Team** – team in possession, **ID** – simplice unique ID, **Location** – simplice qualitative location, **Synchronisation value** – simplice synchronisation value for the different analysis variables.

2.5 Model and statistical methods

The effect of different variables on the synchronisation values is assessed using two different methods: pairwise difference between means and pairwise rank differences. Due to the skewed distribution and size of the dataset, the statistical significance, *p*-value (two-sided), for the differences between means is computed via a permutation test method [23], using the stats.permutation_test function from SciPy 1.15.1 module for Python 3.11.1.

In the case of rank differences, the Brunner-Munzel statistic is used due to the different variances between the compared sets [24, 25]. The statistic value, *W,* its degrees of freedom, *df*, and *p*-value (computed with the two-sided *t* statistic) are computed using the stats.brunnermunzel function from SciPy 1.15.1 module for Python 3.11.1.

For the study on how the synchronisation value varies between analysis variables and simplex locations the average of the synchronisation value is computed at each qualitative location over all frames, possession team, and simplice ID.

For assessing the statistical significance of the differences between the synchronisation averages across locations a generalized linear mixed effects model is used, as described by Equation (1):

$$\varphi_{ji} = \ln\left(\frac{Y_{ji}}{1-Y_{ji}}\right) = \beta_0 + \sum_{j=1}^{N_i} \beta_i X_{ji} + u_{0i} + \varepsilon_{ji} \quad (1)$$

Here, we use the logit transformation, φ_{ji}, of the synchronisation value, i.e., the dependent (response) variable, $Y_{ji} \sim \text{Beta}(\alpha, \beta)$, and *i* is the frame index for simplice with ID *j*.

The two fixed independent factors (predictors) are the categorical variables indicating the longitudinal and lateral field zone, $cx \in \{DEF1, DEF2, MID1, MID2, ATT2, ATT1\}$ and $cy \in \{LFT2, LFT1, RGT1, RGT2\}$, the simplice ID, i, being used as random factor. The intercept, β_0, corresponds to pair $(cx, cy) = (MID2, LFT1)$ and X_{ji} is obtained from the indicator function on all other possible values for (cx, cy). To consider the interaction between factors cx and cy, indicator functions on their joint values are also considered. Random variables $u_{0i} \sim \mathcal{N}(0, \omega^2)$ and $\varepsilon_{ji} \sim \mathcal{N}(0, \sigma^2)$ correspond, respectively, to the by-subject, i.e., simplice ID, random intercepts, and the sample-level model estimate error (residuals), for which normal distributions are assumed.

Procedures for computing both simplices' hyperedges and the analysis variables were performed using routines created by the authors, coded in GNU Octave version 4.4.1 and applied to each match frame sample. The regression model estimation and its statistical analysis were performed using R version 4.3.2 and the lme4 version 1.1.35 library.

3 Results

3.1 Synchronisation tendencies: Distance and angle to the goal

Overall, synchronisation tendencies varied according to field location and reference goals. When comparing synchronisation tendencies between the angle and the distance to the goal, there is a tendency for distance to the goal to elicit higher synchronisation tendencies. Additionally, the distance to the goal elicited a more uniform distribution of synchronisation across the playing field, while the angle to the goal revealed higher synchronisation tendencies in the side corridors.

When analysing the value of distance to the attacked goal (Figure 3a) and the defended goal (Figure 3d), synchronisation tendencies were found to be higher in areas closer to each goal, especially near the goal being attacked. Differences in synchronisation tendencies in different areas of the field *in between* the attacked and defended goals are minimal, as shown in Figure 3g.

Regarding the angle to the attacked goal (Figure 3b) and the defended goal (Figure 3e), higher synchronisation tendencies were observed in the side corridors, with a tendency for increased values near the reference goals in each analysis. Comparing synchronisation tendencies between the angle to the attacked goal and the defended goal (Figure 3h), greater differences were observed compared to the distance to the goal.

Differences between player synchronisation tendencies, relative to distance to the attacked goal and to angle to the attacked goal (Figure 3c), are accentuated in the central corridor and areas near the defended goal. In turn, differences between synchronisation tendencies of distance to the defended goal and of angle to the defended goal (Figure 3f), are more pronounced in areas near the attacked goal.

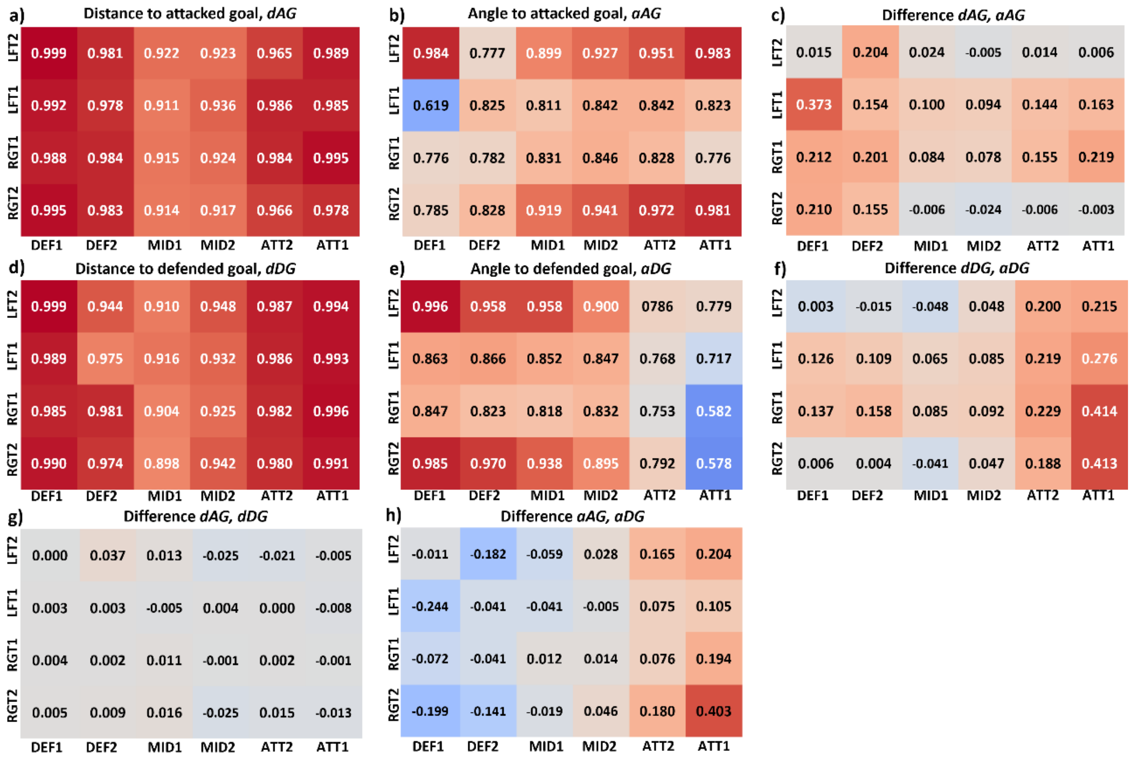

Figure 3. Illustration of heat-maps representing the simplice synchronisation tendencies regarding: a) distance to attacked goal; b) angle to attacked goal; c) differences between distance and angle to attacked goal; d) distance to defended goal; e) angle to defended goal; f) differences between distance and angle to defended goal; g) differences between distance to attacked goal and defended goal; h) differences between angle to attacked goal and defended goal. Values of synchronisation range from 0 (unsynchronised behaviour) to 1 (complete synchronised behaviour). The direction of the goal being attacked is from left to right.

3.2 Differences between the traditional coordinate system (lateral and longitudinal orientations) and the novel coordinate system (angle and distance to the goal)

3.2.1 Lateral Orientation vs Angle

Analysing synchronisation tendencies constrained by the lateral (y-axis) variable (Figure 4a), it is evident that the highest values were observed in the side corridors of the field, approximating results from analysis of the angle to goal (Figures 4b and 4d). However, a more detailed comparison between these two variables reveals considerable differences, whether in the side corridors or other areas (like the central corridor). The fact that the angle to the goal separately considers both attacked and defended goals as reference points in the analysis may be a key factor contributing to the observed differences in synchronisation values (detailed results are provided in Tables 4 and 5 of the supplementary materials).

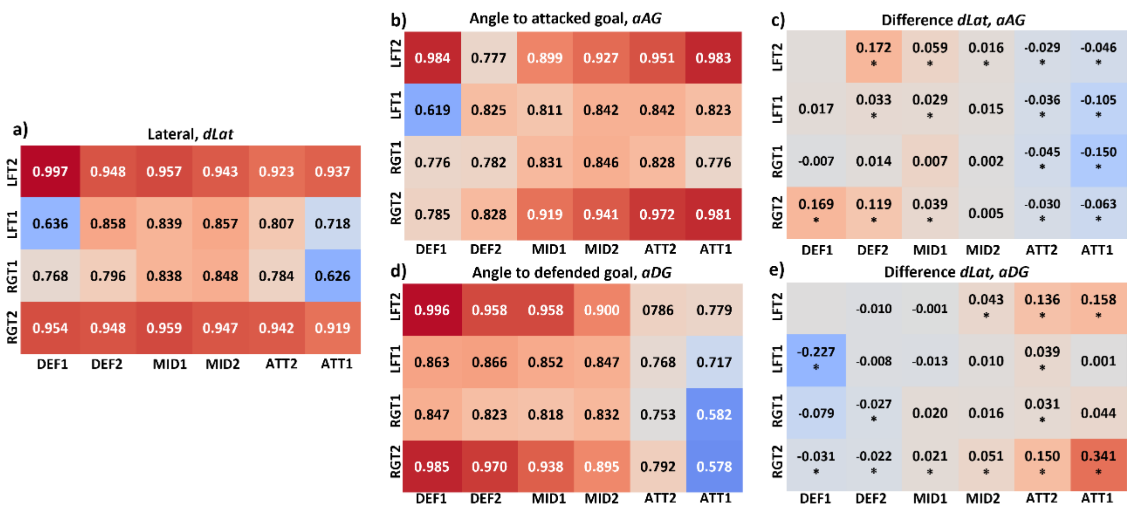

Figure 4. Illustration of heat-maps representing synchronisation tendencies regarding: a) lateral orientation on field (y-axis); b) angle to attacked goal; c) differences between lateral (y-axis) orientation and angle to attacked goal; d) angle to defended goal; e) differences between lateral (y-axis) orientation and angle to defended goal. Values of synchronisation range from 0 (unsynchronised behaviour) to 1 (complete synchronised behaviour). The direction of the goal being attacked is from left to right. *Areas in which statistically significant differences were observed.

3.2.2 Longitudinal Orientation vs Distance

Regarding the synchronisation tendencies between the longitudinal (x-axis) orientation variable (Figure 5a) and the distance to the goal (Figure 5b and 5d), similar values were observed, resulting in minimal differences across various areas of the field, as shown in Figures 5c and 5e (detailed results are provided in Tables 6 and 7 of the supplementary materials).

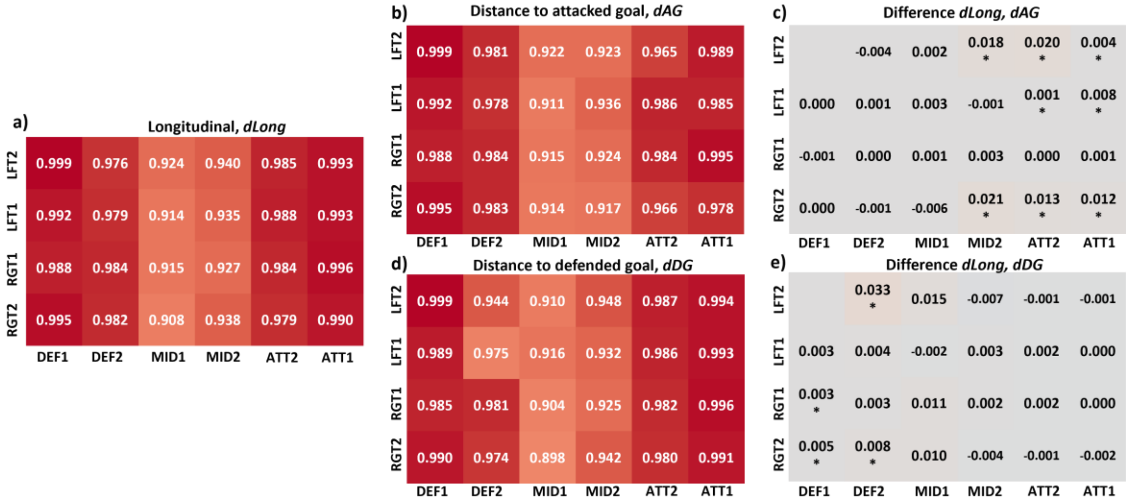

Figure 5. Illustration of heat-maps representing the synchronisation tendencies regarding: a) longitudinal (x-axis) orientation; b) distance to attacked goal; c) differences between longitudinal (x-axis) orientation and distance to attacked goal; d) distance to defended goal; e) differences between longitudinal (x-axis) orientation and distance to defended goal. Values of synchronisation range from 0 (unsynchronised behaviour) to 1 (complete synchronised behaviour). The direction of the goal being attacked is from left to right. *Areas in which statistically significant differences were observed.

3.3 Differences within field zones

Figures 6a and 6b indicate significant differences in average synchronisation tendencies within each specific area of the field, constrained by the different variables. Among the 24 zones into which the field was divided, the angle to the defended goal (Figure 6a: blue balls + two colour balls) shows the greatest variation, with significant differences in nine zones. The values of distance, relative to the attacked and defended goals separately, present fewer differences between synchronisation averages, with the greatest impact on distance to the attacked goal (Figure 6b: white balls + two colour balls), with significant differences in seven zones.

These findings highlight the importance of understanding the events emerging in each area of the field, particularly in identifying the most prevalent simplice structures, and how they influence the synchronisation tendencies obtained.

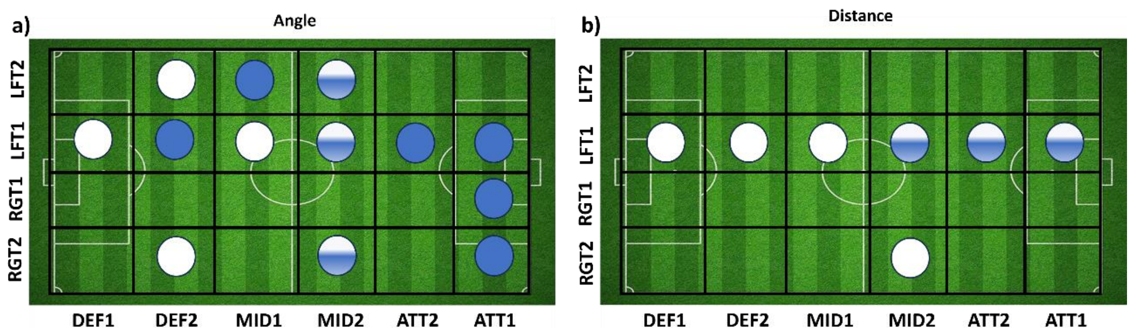

Figure 6. Illustration of a football field divided into 24 zones, represented by coloured balls indicating areas with statistically significant differences in synchronisation averages, considering: a) angle; b) distance. White balls represent zones with differences only at the attacked goal. Blue balls represent zones with differences only at the defended goal. Two-colour balls represent the zones with differences at both the attacked and defended goals.

To facilitate understanding, a detailed analysis of differences in synchronisation tendencies across different areas of the field was conducted. Table 2 presents the model estimated parameters for the angle to the attacked and defended goals (a_{AG} and a_{DG}), while Table 3 refers to the distance to the attacked and defended goals (d_{AG} and d_{DG}) analysis variables.

Table 2

Model parameters considering the angle to the attacked and defended goal, a_{AG} and a_{DG}

Field Zone, X_{ji}	Estimate, β_i		Std. Error		z value		Pr(>|z|)	
	a_{AG}	a_{DG}	a_{AG}	a_{DG}aDG	a_{AG}	a_{DG}	a_{AG}	a_{DG}
(Intercept)	**1.428**	**1.370**	0.039	0.039	36.780	35.140	**<.001**	**<.001**
cxATT2	0.088	**-0.310**	0.054	0.053	1.630	-5.880	0.103	**<.001**
cxATT1	0.038	**-0.480**	0.084	0.081	0.460	-5.940	0.648	**<.001**
cxMID1	**-0.169**	0.061	0.048	0.049	-3.500	1.240	**<.001**	0.214
cxDEF2	-0.109	**0.248**	0.067	0.069	-1.610	3.610	0.106	**<.001**
cxDEF1	**-0.610**	*0.376*	0.162	0.174	-3.770	2.160	**<.001**	*0.031*
cyLFT2	**0.520**	**0.450**	0.055	0.054	9.450	8.270	<.001	<.001
cyRGT1	0.057	-0.022	0.046	0.046	1.250	-0.480	0.210	0.633
cyRGT2	**0.790**	**0.525**	0.058	0.058	13.510	9.090	**<.001**	**<.001**
cxATT2:cyLFT2	0.153	*-0.264*	0.088	0.085	1.740	-3.110	0.082	*0.002*
cxMID2:cyLFT2	*0.319*	-0.234	0.150	0.141	2.130	-1.660	*0.034*	0.097
cxMID1:cyLFT2	0.017	**0.308**	0.079	0.080	0.210	3.850	0.834	**<.001**
cxDEF2:cyLFT2	**-0.582**	0.205	0.130	0.135	-4.490	1.520	**<.001**	0.128
cxDEF1:cyLFT2	0.908	-1.184	1.088	1.083	0.830	-1.090	0.404	0.274
cxATT2:cyRGT1	-0.038	0.037	0.076	0.075	-0.500	0.490	0.620	0.624
cxATT1:cyRGT1	-0.105	**-0.413**	0.116	0.113	-0.910	-3.660	0.365	**<.001**
cxMID1:cyRGT1	0.027	-0.124	0.069	0.069	0.390	-1.790	0.697	0.073
cxDEF2:cyRGT1	*-0.233*	-0.113	0.094	0.096	-2.490	-1.180	*0.013*	0.238
cxDEF1:cyRGT1	0.216	-0.275	0.213	0.226	1.010	-1.220	0.310	0.223
cxATT2:cyRGT2	0.119	-0.127	0.098	0.094	1.210	-1.350	0.225	0.178
cxATT1:cyRGT2	0.275	**-1.144**	0.228	0.209	1.200	-5.460	0.229	**<.001**
cxMID1:cyRGT2	-0.206	-0.009	0.088	0.088	-2.340	-0.100	0.019	0.922
cxDEF2:cyRGT2	**-0.725**	0.202	0.118	0.121	-6.140	1.680	**<.001**	0.094
cxDEF1:cyRGT2	*-0.527*	0.239	0.223	0.242	-2.370	0.990	*0.018*	0.323

Note: “Field zone” column indicates different field zones.
E.g. (Intercept) corresponds to $(cx, cy) = (MID2, LFT1)$; “cxDEF2” corresponds to $(cx, cy) = (DEF2, LFT1)$; “cxDEF2:cyRGT2” corresponds to the interaction between cx and cy at $(cx, cy) = (DEF2, RGT2)$. Significance level: **<.001**, *.001<<.050*

Table 3

Model parameters considering distance to the attacked and defended goal, d_{AG} *and* d_{DG}

Field Zone, X_{ji}	Estimate, β_i		Std. Error		z value		Pr(>|z|)	
	d_{AG}	d_{DG}	d_{AG}	d_{DG}aDG	d_{AG}	d_{DG}	d_{AG}	d_{DG}
(Intercept)	**2.404**	2.440	0.039	0.038	61.870	64.120	**<.001**	**<.001**
cxATT2	**0.392**	0.451	0.054	0.053	7.260	8.450	**<.001**	**<.001**
cxATT1	**0.564**	0.679	0.084	0.084	6.690	8.080	**<.001**	**<.001**
cxMID1	**-0.159**	*-0.117*	0.047	0.047	-3.380	-2.480	**<.001**	*0.013*
cxDEF2	**0.266**	*0.194*	0.069	0.068	3.860	2.840	**<.001**	*0.004*
cxDEF1	**0.606**	*0.580*	0.183	0.180	3.310	3.230	**<.001**	*0.001*
cyLFT2	*-0.136*	0.020	0.053	0.052	-2.580	0.380	*0.010*	0.705
cyRGT1	-0.036	-0.043	0.045	0.044	-0.810	-0.980	0.417	0.329
cyRGT2	**-0.200**	-0.014	0.055	0.055	-3.630	-0.250	**<.001**	0.800
cxATT2:cyLFT2	-0.160	-0.025	0.086	0.086	-1.850	-0.300	0.064	0.767
cxATT1:cyLFT2	-0.074	-0.181	0.149	0.147	-0.500	-1.230	0.620	0.218
cxMID1:cyLFT2	*0.195*	*-0.153*	0.076	0.075	2.550	-2.030	*0.011*	*0.043*
cxDEF2:cyLFT2	0.142	*-0.318*	0.132	0.129	1.070	-2.480	0.283	*0.013*
cxDEF1:cyLFT2	0.089	0.107	1.068	1.064	0.080	0.100	0.933	0.920
cxATT2:cyRGT1	-0.002	-0.075	0.076	0.075	-0.030	-1.000	0.978	0.319
cxATT1:cyRGT1	0.153	0.086	0.120	0.118	1.280	0.730	0.202	0.468
cxMID1:cyRGT1	0.099	0.030	0.067	0.067	1.470	0.450	0.142	0.651
cxDEF2:cyRGT1	0.112	0.144	0.096	0.095	1.160	1.520	0.245	0.130
cxDEF1:cyRGT1	0.139	-0.027	0.234	0.230	0.590	-0.120	0.552	0.906
cxATT2:cyRGT2	-0.113	*-0.240*	0.095	0.095	-1.200	-2.540	0.232	*0.011*
cxATT1:cyRGT2	-0.211	-0.149	0.225	0.227	-0.940	-0.660	0.350	0.512
cxMID1:cyRGT2	*0.272*	-0.036	0.084	0.084	3.230	-0.430	*0.001*	0.667
cxDEF2:cyRGT2	*0.300*	0.014	0.119	0.118	2.520	0.120	*0.012*	0.903
cxDEF1:cyRGT2	0.201	-0.320	0.246	0.242	0.820	-1.320	0.414	0.185

Note: “Field zone” column indicates different field zones.

E.g. (Intercept) corresponds to $(cx, cy) = (MID2, LFT1)$; “cxDEF2” corresponds to $(cx, cy) = (DEF2, LFT1)$; “cxDEF2:cyRGT2” corresponds to the interaction between cx and cy at $(cx, cy) = (DEF2, RGT2)$ Significance level: **<.001**, *.001<<.050*

4 Discussion

This study aimed to explore a novel method for analysing meso-level player synchronisation tendencies, using a newly developed coordinate system, defined by the performance variables of angle and distance of simplices relative to each goal. Importantly, the study did not seek to assess specific synchronisation tendencies as inherently more or less effective in achieving performance outcomes. Instead, the focus was to explore how such patterns reflect the adaptive behaviours of teams in response to competitive constraints, that is, how the synchronisation of movements between players – teammates or opponents – varies based on their positioning on the field concerning the distance and angle to the goal.

Results obtained from this approach demonstrate an enhanced sensitivity of the proposed system in detecting synchronisation tendencies, particularly when compared to the traditional coordination system. Indeed, while synchronisation tendencies appear similar when comparing longitudinal and distance variables, more pronounced differences emerge when constrained by the lateral and the angle to the goal. Importantly, this novel approach is not intended to replace the traditional longitudinal-lateral Cartesian coordinate system but rather to complement it, as each offers specific insights into player coordination dynamics. Together, their combined use can provide a more comprehensive understanding of how players synchronise movements during performance than either approach alone.

A distinctive contribution of this study lies in the adoption of ecological variables – namely, players' distance and angle to each goal – as the reference frame for assessing synchronisation tendencies. Unlike the more neutral Cartesian coordinates (x, y), which describe movements in purely geometric terms, ecological variables are inherently grounded in the functional relations between players and key elements of the performance environment. This relational coordinate system embeds tactical and informational relevance into the measurement process, enabling synchronisation values to reflect how players adapt their positioning and movements to affordances such as goal location, pitch areas, and the co-positioning of teammates and opponents. In doing so, the method bridges spatial measurements with their performance meaning, offering an ecologically valid lens for examining coordination in football.

First, the synchronisation results, assessed through the distance to the goal, show that synchronisation tendencies are higher in areas closer to each goal, and particularly near the attacked goal. These findings contrast those reported by Carrilho et al. [1] and López-Felip et al. [26], who observed that when the ball was located in central areas of the field near the attacked goal, the mean synchronisation values decreased. Typically, near the attacked goal, the attacking player's space-time interactions are limited due to the proximity of defenders, who prioritize control of critical spaces to neutralize passing or shooting opportunities that could lead to a conceded goal. Conversely, to overcome these spatial-temporal constraints, attackers need to attract defenders, alternate between horizontal and vertical passes, increase the pace of ball circulation, and perform crosses from wide areas to generate goal-scoring opportunities. Depending on a team's strategy, a key performance objective may involve employing a low block (i.e., reducing space-time interactions to block the opponents' progression) or to transition into attack in the opposite direction of play, which will influence player synchronisation values accordingly.

Second, when analysing the angle to the goal, higher synchronisation tendencies were observed in the side corridors of the field, especially near the reference goals. These findings suggest that players prioritise controlling space relative to opponents in these areas by coordinating their movements with teammates (co-adapting), as captured by the angle-to-goal variable. It is important to note that near the goals, larger angular amplitudes are associated with slower rates of angular change, which may mechanically favour higher synchronisation values. However, this geometric characteristic aligns with tactical contexts in which players tend to stabilise their positioning (e.g., when defending the goal area or preparing for a set piece delivery), thereby reinforcing the emergence of coordinated patterns. Such insights shed light on the emergence of group synergies [27], demonstrating how players synchronise their behaviors during game situations, primarily through coordinated diagonal movement patterns directed toward the attacking or defending goals (e.g., in 1 vs. 1 situations when the ball carrier attempts to dribble past a defender from the outside toward the inside corridor to create a passing or shooting opportunity).

Variations in synchronisation values suggest continuous adaptations influenced by the adapter component and driven by local interactions between players, within and between teams. These self-organizing tendencies, observed at the level of simplices, highlight the emergence of functional synergies, in which players co-adapt their behaviours based on locally created information (affordances), enabling them to regulate their positioning and movements in response to both teammates and opponents[12]. Crucially, these synchronisation patterns should not be interpreted as neutral or merely structural. Instead, they reflect emergent properties of goal-directed co-adaptive behaviours. That is, players continuously adjust their actions in a purposeful way to sustain or disrupt the flow of the game in relation to competitive objectives – such as maintaining possession, creating space, advancing towards the goal, or preventing the opponent from doing so.

By using distance and angle to the goal as analysis variables, we capture precisely this functional, goal-oriented nature of coordination. Synchronisation in distance to the goal, particularly near the goals, may reflect efforts to maintain structural compactness or control of critical zones. In turn, variations in the angle to the goal, observed between the central and side corridors, may suggest exploratory behaviours as teams search for varied tactical solutions aimed at penetrating defensive lines or shifting the attacking direction. In this sense, synchronisation is not an end in itself, but a process through which teams maintain their collective organisation while remaining adaptable to emerging performance constraints. These dynamics embody the balance between structural stability and tactical flexibility, which lies at the heart of effective team performance [27]. However, further analysis is needed to draw more robust conclusions.

From the perspective of collective homeostasis, it is important to recognise that the regulatory objectives of attackers and defenders are not symmetrical[13, 28]. Defending players typically seek to preserve structural stability by constraining space and limiting the opponent's attacking affordances—thus acting as agents of homeostasis. In contrast, attacking players aim to disrupt this equilibrium by creating instability through deception, space manipulation, and the destabilisation of defensive structures. Synchronisation tendencies, therefore, may reflect either stabilising or destabilising processes depending on the functional role of the players within the game phase. For instance, high synchronisation in defence may indicate cohesive space control, while transient desynchronisation in attack may be functional in provoking defensive imbalance and enabling goal-scoring opportunities. This conceptual distinction reinforces the idea that synchronisation should not be interpreted as uniformly desirable or effective but rather understood as a context-dependent expression of adaptive behaviour.

The model of collective homeostasis [13, 28] highlights this perspective by framing team coordination as a self-regulatory process to preserve functionality against continuous imbalances. Within this framework, variability is inevitable and essential, fostering resilience and adaptability to changing performance demands (e.g., Davids et al. [29]).

5 Limitations and future directions

As this is a case study, these variations highlight the challenge of generalizing findings across contexts, as what proves effective for one team or scenario may not apply universally. The study's limitations include a small sample size, the absence of ball data, and the lack of a direct relationship between the proposed synchronisation method and performance indicators, such as the number of ball recoveries or the creation of goal-scoring opportunities.

Despite these limitations, the method grounded in the collective homeostasis model provides promising avenues for future research. These include detailed examinations of synchronisation tendencies related to simplice structures in different field zones, considering the zonal differences observed across the analysed variables. In this context, exploring alternative spatial divisions beyond the 24 zones used in this study could be valuable to analyse the types of relational structures emerging during competitive performance. Recognising that different types of simplices can emerge throughout competitive performance (e.g., Ribeiro et al. [31]), it would be valuable to explore how such structures influence synchronisation tendencies. Moreover, because synchronisation tendencies are known to vary across teams and contexts – being influenced by factors such as playing style, team system, player characteristics, and competition level [32, 33] – future studies should investigate how these contextual variables shape the emergence and stability of synchronised behaviours. Furthermore, it would be relevant to explore whether synchronisation tendencies are associated with more frequent ball recoveries in specific field zones, depending on particular team structures, or whether synchronous or asynchronous tendencies increase the probability of scoring by disrupting defensive organisation.

6 Conclusions

This study introduced a novel methodological approach to identify meso-level synchronisation processes in competitive football, focusing on the continuous adaptive demands of homeostatic regulation. The key findings highlight that the angle and distance to the goal comprise relevant variables influencing synchronised player behaviours during competitive performance. The method provides valuable insights into team self-organization by revealing synchronisation tendencies and the specific locations where each relational structure emerges. These findings are relevant for performance analysis, as they uncover key interaction patterns and spatial dynamics that can support tactical decisions-making and the design of more effective training sessions.

Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability statement

Raw output data from this research are available upon reasonable request to the corresponding author.

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