A multilevel hypernetworks approach to capture meso-level synchronisation processes in football

RIBEIRO, Joao, LOPES, Rui, SILVA, Pedro, ARAUJO, Duarte, BARREIRA, Daniel, DAVIDS, Keith <http://orcid.org/0000-0003-1398-6123>, RAMOS, Joao, MAIA, Jose and GARGANTA, Julio

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Title: A multilevel hypernetworks approach to capture meso-level synchronisation processes in football

Ribeiro J., Lopes R., Silva P., Araújo D., Barreira D., Davids K., Ramos J., Maia J., & Garganta J.

Abstract

Understanding team behaviours in competitive sports performance requires a robust understanding of the interdependencies established between their levels of complexity in organisation (micro-meso-macro). Previously, most studies have tended to examine interactions emerging at micro- and macro-levels, thus neglecting those emerging at a meso-level (a level which reveals connections between the micro and macro levels, depicted by the emergence of coordination in specific sub-groups of players during performance). We addressed this issue using the multilevel hypernetworks approach, adopting a cluster phase method, to record player-simplice local synchronies in two performance conditions where the number, size and location of goal scoring targets were manipulated (1st–condition: 6x6+4 mini-goals; 2nd–condition: Gk+6x6+Gk). We investigated meso-level coordination tendenciesas a function of ball-possession (attacking/defending), field-direction (longitudinal/lateral) and teams (Team A/Team B). Univariate Anova was used to assess the cluster amplitude mean values that emerged between game conditions, as a function of ball-possession, field-direction and team composition. Generally, large synergistic relations and more stable patterns of coordination were observed in the longitudinal direction of the field than the lateral direction for both teams, and for both game phases in the first condition. The second condition displayed higher synchronies and more stable patterns in the lateral direction than the longitudinal plane for both teams, and for both game phases. Results suggest: (i) usefulness of hypernetworks in assessing synchronisation of teams at a meso-level; (ii) coaches may consider manipulating the number, location and

size of goals to develop levels of local tendencies for emergent synchronies within teams.

Keywords: Multilevel hypernetworks, Meso-level, Emergent Synchronisation tendencies, Team sports, Association football.

Introduction

Sports teams consist of social entities composed of individual agents who correlate and coordinate actions to establish effective team communication networks (Gonçalves et al., 2017; Ribeiro et al., 2017).

The synergetic behaviours (i.e., players combine actions to produce goal-oriented behaviours) that underlie the formation and development of such communication networks can be expressed at different levels of complexity. Typically, there are three general levels of complexity into which networks may typically fall: the micro-, meso- and macro-levels. The micro-level focuses essentially on the relationships that each player has with other players in a team, while the meso-level sheds light on the interpersonal synergies emerging between small groups of players coordinating actions together during performance. Finally, the macro-level tends to consider the whole structure of social interactions emerging within a team and how it relates to team performance outcomes.

The interdependence of team players' behaviours and actions suggests that all three levels are interconnected. For example, players at a micro-level might interact with their nearest team members (at a meso-level), under n-ary interpersonal relations to produce more complex sets of behaviours or patterns emerging at a macro-level. Typically, the majority of previous studies has tended to focus on the relations established at a micro-level (dyads, i.e., relations established between pairs of individuals), or at a macro level of team organisation (whole team behaviours organised together). Other research (e.g., Duarte et al., 2013) has focused on the link between micro and macro relations, by measuring the synchronisation processes between such levels. Indeed, the study by Duarte et al. (2013) sought to analyse the movement synchronies evidenced at *player-team* and *team-team* levels. These investigators tried to understand how such synchronisation tendencies varied as a function of key events and characteristics such as transitions in ball possession (attacking/defending), halves of the match (first/second), team status (home/visiting) and field direction (longitudinal/lateral), by means of a cluster phase method (see Frank and Richardson, 2010, for detailed descriptions on this method).

Despite these meaningful theoretical and empirical insights regarding team game performance, research has not yet captured the synchronisation tendencies emerging at a meso-level scale. These processes should not be neglected as they fall between the micro- and macro- levels and can provide relevant information regarding the interconnections established between such levels (e.g., how players interact locally with their nearest teammates to produce regular patterns of behavior during performance). Given the interdependency between levels in a complex system, there is a need to integrate all scales of analysis (micro-to-meso-to-macro) in research on team sports performance (Bar-Yam, 2003; Bar-Yam, 2004).

Despite this gap in the field, there is a clear paucity of studies seeking to propose methods for measuring and providing insights on the processes underlying the establishment of synchronisation processes of players, within and between teams, at a meso-level scale. An exception is the study of López-Felip et al. (2018) which used the cluster phase method (CPM) to capture team coordination by analysing players' behavioral variables (players' orientation-to and distance-to goal). Most previous studies (e.g., Folgado et al., 2018; Gonçalves et al., 2018) have used phase synchronisation (players viewed as "oscillators") to assess coordination between players. Nonetheless, it is worth mentioning that phase synchronisation is just one of the many metrics and/or methods that can be used to assess coordination between cooperating and competing players (see, for example, generalised synchronisation (e.g., Rulkov et al., 1995), or granger causality (e.g., Kirchgässner & Wolters, 2007)). Recent developments in network analyses applied to team sports performance have led to the introduction of a novel methodology: multilevel hypernetworks (Ramos et al., 2017; Ribeiro et al., 2019). This approach shows signs of helping researchers ascertain the complexity rooted at such levels of team coordination processes.

Therefore, in this study, we sought to extend the previous analysis of Duarte et al. (2013) by proposing a multilevel hypernetworks approach for capturing the movement synchronies of players at a meso-level scale. Moreover, we aimed to analyse whether such synchronisation tendencies changed between game conditions (1st condition – 6x6 (6 vs. 6 players) +4 mini-goals; 2nd condition – Gk+6x6+Gk (goalkeeper plus 6 players vs. goalkeeper plus 6 players)). These manipulations involved the location, number and size of goal scoring targets. We also investigated these tendencies a function of ball-possession (attacking/defending), field direction (longitudinal/lateral) and different teams (Team A/Team B). Our hypotheses are as follows: (i) the first condition will result in the emergence of greater synchronisation and more stable patterns of coordination in the longitudinal direction, compared to the lateral direction of the field. This effect may be due to the absence of goalkeepers, as well as the lack of an offside rule and the increased number of goals/targets; (ii) The second condition will result in the emergence of greater, and more stable, coordination tendencies in the lateral direction of the field, compared to the longitudinal direction, due to a) the location of the goal/scoring target (located in the centre of the field), and b), the presence of the goalkeeper.

Methods

Participants

Fourteen male youth football (soccer) players registered with an U19 yrs squad (mean age 17,9 ± 0,7 years, mean height 175,6 ± 5,7 cm, mean weight 69,7 ± 9,9 Kg, and training experience: 9,2 ± 2,9 years), competing at a regional level, were recruited to participate in this study. All participants gave prior informed consent before initiating the experiment. All procedures followed the guidelines of the Declaration of Helsinki and were in accordance with the ethical standards of the lead institution.

Task and procedures

This study was conducted over a two-week period during the 2017/2018 competitive season. Participants performed in two game conditions in which the number, location and size of goals were manipulated. Each game was preceded by a 10-minute standardised warm-up composed of low-intensity running, ball-passing actions and dynamic stretches. All these activities were part of the regular training sessions that players were involved with. The first game condition (conducted in the first week) consisted of two 6-a-side (6vs.6) games without Goalkeepers (Gk), where players from opposing teams were solicited to attack/defend two mini-goals sized 0,90 x 0,90 m (height x width) located in both right- and left-hand sides of the pitch (Figure 1a). The second game condition (conducted in the second week) comprised two 6-a-side plus Gk (Gk+6vs.6+Gk) games with two football goals sized 6 x 2 m (height x width) centered on the end line of the pitch (Figure 1b). The players were split by the team coaches into two technically-balanced teams. In the first condition, players were organised on field according to a 2-3-1 tactical disposition, with 1 right central defender (RCD), 1 left central defender (LCD), 1 left midfielder (LM), 1 right midfielder (RM), 1 central midfielder (CM), and 1 forward (FW). In the second condition, the organisation of players on field was similar to the first condition, but now with the inclusion of a goalkeeper (Gk) (1-2-3-1). The objective of teams in both game conditions was to score as many goals as possible while preventing the opposing team from scoring. The respective field dimensions of the playing area in both conditions (63, 6 x 40,7 m, height x width) were obtained based on the minimum dimensions permitted by the *International Football Association Board* (100x64 m, height x width), and the number of players involved in each game (Hughes, 1994).

Please insert Figure 1 near here

Figure 1. Experimental task schematic representation: a) 6x6+4 mini-goals condition; b) Gk+6x6+GK condition.

Each match had a duration of 15 minutes interspersed by a recovery interval of 7 minutes to minimise the influence of fatigue on participants. During recovery periods, players could recovery at will and rehydrate. Additionally, during this period, players were asked to respond to the Borg Rating of Perceived Exertion (RPE) Scale (Borg, 1982). The RPE was utilised with verbal anchors, which comprehended a 15-grade scale ranging from 6 (minimum effort) to 20 (maximum effort) (Borg, 1982), with players being asked the following: “how do you classify the physical effort in the task from 6 (minimum effort) to 20 (maximum effort)?” Moreover, all matches were undertaken at the same hour of the day (19:00 pm) in order to prevent possible circadian effects on performance (Cappaert, 1999). Several balls were placed around the pitch to prevent trial stoppages. Additionally, coaches were instructed to not provide any sort of encouragement and/or feedback to the players, before and during practice, since it can influence levels of practice intensity in individual participants, thus affecting performance (Rampinini et al., 2007).

Data collection

Positional data (x, y) were acquired through utilisation of global positioning tracking devices (Qstarz, Model: BT – Q1000Ex) at 10Hz, placed on the upper back of each player. Previous studies have confirmed the usefulness and reliability of such GPS devices (e.g., Silva et al., 2016). All pitches were calibrated using the coordinates of four GPS devices stationed at each corner of the pitch for about 4 min. 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 the GPS signals. These absolute positions were used to set the Cartesian coordinate systems for each pitch, with the origin placed at the pitch center. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). A GoPro Rollei Ac415 actioncam (Rollei GmbH & Co. KG, Norderstedt, Germany) was utilised to record and capture players' interactions on field, which encompassed the following characteristics: (i) resolution: FullHD; (ii) processing capacity of 30Hz; (iii) maximum lens aperture: F=2.4; (iv) sensor type: CMOS; (v) capture angle: 140º. The Gopro was stationed on a higher level above the pitch (approximately 4 m high) to ensure an optimal viewing angle (allowing views of the entire field) during the games.

Hypernetworks approach

Hypernetworks extend the concept of hypergraphs to model interactions of a set of elements (e.g., the players) that make up a given system (e.g., a football team). In mathematics, a hypergraph consists of a generalisation of a graph (a structure composed by a set of elements that may share some type of relation) in which an edge can connect any number of nodes. Therefore, a hypergraph H corresponds to a pair H=(X, E) where X encompasses a set of elements called nodes/vertices, while E comprises a set of non-empty subsets of X named hyperedges (Johnson, 2009). Hyperedges can connect more than two nodes (i.e., the players), thus they support representation of simultaneous n-ary relations (n>2), be it cooperative and/or competitive, established between a given set of players (called simplex, plural–simplices) (Johnson & Iravani, 2007; Johnson, 2016; Ramos et al., 2017). A hypersimplex is effectively a hypergraph edge where the relation between the elements is explicit. This is necessary because, for example, three players may collaborate in one 3-ary relational configuration when scoring a goal, but in a completely different 3-ary relational configuration when trying to win back the ball from opposition. A hypernetwork is defined as a set of hypersimplices (for more details, please see Johnson, 2016). Thus, by adopting the hypernetworks approach we were able to assess how players synchronise their movements in relation to the simplices (intra and inter relationships) that they interacted with during competition (see Figure 2). This is a major advantage compared with simply measuring the synchronisation of players' phases, since it is now possible to assess the synchronisation emerging within and between simplices. These simplices can capture the interactions between sets of players that may include an arbitrary number of teammates and opponents. The criteria chosen for selecting the set of nodes was based on the geographical proximity (non-parametric) between players (i.e., a player does interact with his nearest player and/or goal for goalkeepers (2nd condition) and mini-goals for players (1st condition)) and directional speed of players that enable them to interact (through disaggregation and/or aggregation) with other simplices (Ramos et al., 2017). In short, the hypernetworks approach allowed us to assess the synchronies evidenced in intra- and inter-team relationships between players during competition.

Please insert Figure 2 near here

Figure 2. Example of an illustration of hypernetworks representing simplices' interactions in an association football pitch, retrieved from performance in the first game condition (6x6+4 mini-goals). The 4 mini-goals (1 and 2 for Team A; 15 and 16 for Team B) are represented by black dots. Team A (represented in

blue) is attacking from left to right and Team B (represented in red) is attacking from right to left. Each simplex is represented by the polygon (or a line when only two players are involved, e.g., players 7 and 14) defining the convex hull that connects the players (identified by numbers, or goals – identified by black points). Players can also be linked to the goals due to the proximity-based criteria (e.g., player 6 and 3 from the blue team and player 10 from the red team are connected to the mini-goal number 2). A velocity vector for each player is also represented.

Cluster phase method

Frank and Richardson (2010) proposed the CPM by adapting the model from the Kuramoto order parameter (Kuramoto & Nishikawa, 1987). Such a model was originally developed for analysing systems whose oscillatory unit's number tended to infinity (Strogatz, 2000). Frank and Richardson (2010) decided to test the applicability of the same model in analysing systems composed by a small number of oscillatory units (a multiple-rocking chair experiment with only six oscillatory units).

Basically, the CPM allows the calculation of the mean and continuous group synchrony, ρ_{group} and $\rho_{group}(t_i)$, as well as the individual's relative phase, θ_k, in regard to the group measure (Richardson et al., 2012). This method has been used in a study by Duarte et al. (2013) to assess whole team synchrony (at a macro-scale level) and player-team synchrony (at a micro-scale level) in a professional football match. Implementation of this method allowed them to calculate a global measure, the cluster amplitude $\rho_{group}(t_i)$, depicting the team synchronisation at every instant time of the match. It also supported use of a relative phase measure reporting the level of individual player's synchronisation with respect to the team, $\emptyset_k(t_i)$.

A major advance proposed in the present study, compared to that of Duarte et al. (2013), is that we introduced a multilevel hypernetworks approach to assess the synchronisation processes emerging at a micro-to-meso level depicted through measurement of player-simplices (P-S) synchronisation. To achieve that aim, we assessed how each player synchronises his movements with the corresponding simplices into which he is inserted.

The extension to other groups, i.e. player sets, beyond teams is supported by the following generalisations to the definitions and equations presented by Duarte et al. (2013).

These procedures starts with the phase time-series acquired through Hilbert transformation, $\theta_k(t_i)$, for the k^{th} player movements measured in radians [-π π], where $k = 1, \cdots, N$ and $i = 1, \cdots, T$ time steps. In the generalisation proposed in the current study we use the definition of group, Γ_j. These groups correspond to the different hypernetworks' player sets. For each group, Γ_j its size, n_j, is defined by the number of players that compose that group (i.e., simplex).

Using this generalisation, the group cluster phase time-series, $\overline{\emptyset}_j(t_i)$, can be calculated as:

$$\acute{r}_j(t_i) = \frac{1}{n_j} \sum_{k \in \Gamma_j} \exp(i\theta_k(t_i)) \ldots\ldots (1)$$

and:

$$\overline{\emptyset}_j(t_i) = atan2(\acute{r}_j(t_i)) \ldots\ldots (2)$$

where $i = \sqrt{-1}$ (when not used as a time step index), $\acute{r}_j(t_i)$ and $\overline{\emptyset}_j(t_i)$ comprise the resulting cluster phase in complex and radian form, respectively.

Finally, the continuous degree of synchronisation of the group $\boldsymbol{\rho}_{\Gamma_j}(\boldsymbol{t_i}) \in [\mathbf{0}, \mathbf{1}]$, i.e., the cluster amplitude $\boldsymbol{\rho}_{\Gamma_j}(\boldsymbol{t_i})$ at each time step t_i can be calculated as:

$$\rho_{\Gamma_j}(t_i) = \left|\frac{1}{\mathrm{n}_j}\sum_{k\in\Gamma_j} \exp(i(\theta_k(t_i) - \overline{\emptyset}_j(t_i)))\right| \quad (3)$$

and the temporal mean degree of group synchronisation, $\boldsymbol{\rho}_{\Gamma_j} \in [\mathbf{0}, \mathbf{1}]$, is computed as:

$$\rho_{\Gamma_j} = \frac{1}{T}\sum_{i=1}^{T} \rho_{\Gamma_j}(t_i) \quad (4)$$

The cluster amplitude corresponds to the inverse of the circular variance of $\emptyset_k(t_i)$. Therefore, on the one hand, if $\rho_{\Gamma_j} = 1$, the group is in complete intrinsic synchronisation. On the other hand, if $\rho_{\Gamma_j} = 0$, the group is completely unsynchronised. Therefore, the larger the value of ρ_{Γ_j} (i.e., close to 1), the larger the degree of group synchronisation. The same expressions can be applied to teams by replacing the simplice sets Γ_j by the set of players of each team Γ_A and Γ_B, respectively.

All the computations were conducted by using dedicated routines implemented in GNU Octave software v4.4.1.

Data analysis

Sample entropy (SampEn) was used to evaluate the regularity of cluster amplitude for each group (P-S) during performance in the two conditioned matches. This nonlinear statistical tool was introduced by Richman and Moorman (2000) and presents the following characteristics: (i) greater consistency with regards to different choices of input parameters; (ii) lower sensitivity to data series length (data length independence), and; (iii) less propensity to statistical bias by eschewing self-matches when compared with traditional approximate entropy (ApEn – Pincus, 1991).

SampEn comprises a modification of ApEn and evaluates the existence of similar patterns in a time-series, thus unveiling the nature of their intrinsic structure of variability (Duarte et al., 2013). Thus, given a series Y(t) of T points (t =1,….,T), SampEn calculates the logarithmic probability that two similar sequences of m points retrieved from Y(t) remain similar. Or, in other words, it evaluates whether the sequences are kept within tolerance bounds given by r, in the next incremental comparison (i.e., for m+1 sequences) (Duarte et al., 2013).

In the current study, input parameters were established as m=1 r=0.2 standard deviations for entropy estimations, as suggested in other investigations of neurobiological system behaviour (e.g., Preatoni et al., 2010; Richman & Moorman, 2000). Values close to zero indicated the presence of regular/near-periodic evolving behaviours for the cluster amplitude regarding the P-S interactions. Higher values of SampEn indicated more unpredictable patterns of synchronisation (Preatoni et al., 2010).

A 2 (game condition) x 2 (ball-possession) x 2 (field direction) x 2 (teams) univariate ANOVA was used to ascertain the cluster amplitude mean values between game conditions, and as a function of ball possession (attacking/defending), field direction (longitudinal/lateral) and teams (Team A/Team B). The repeated measures ANOVA's possible violation of sphericity assumption for the within-participant factors was checked using the Mauchly's test of sphericity. Effect size values were calculated as partial eta square (η2) (Levine & Hullett, 2002). All statistical comparisons were conducted by using the IBM SPSS 24.0 software (IBM, Inc., Chicago, IL); Significance level was set at 5%.

Results

Player-simplice synchronisation

Mean, SD, and SampEn values of P-S cluster amplitude are presented in Table 1. Results revealed significant main effects for teams, ball-possession, and field direction between game conditions.

Table 1. Mean, SD, and SampEn values of P-S cluster amplitude as a function of teams (Team A/Team B), ball-possession (Attacking/Defending), and field direction (Longitudinal/Lateral) for each game condition

Insert Table 1 near here

Between game conditions

Higher mean values of cluster amplitude were found for the longitudinal direction of the field in the attacking phase of the first condition for both Team A (F (1,48224) = 1055,960; p<0,001, η^2=0,021) and Team B (F (1,48224) = 387,406, p<0,001, η^2=0,008), compared to the second condition. Moreover, we observed higher mean values in the lateral direction when attacking in the second condition, for Team A ($F_{(1,48224)} = 1271,121$, $p<0,001$, $\eta^2=0,026$) and Team B ($F_{(1,48224)} = 1352,441$, $p<0,001$, $\eta^2=0,027$), compared to the first condition.

Significant differences for the longitudinal direction of the field when defending were verified in the first condition, for both Team A ($F_{(1,48224)} = 418,547$, $p<0,001$, $\eta^2=0,009$) and Team B ($F_{(1,48224)} = 226,151$, $p<0,001$ $\eta^2=0,005$), when compared to the second condition. Furthermore, we observed higher mean values for the lateral direction for both Team A ($F_{(1,48224)} = 295,393$, $p<0,001$, $\eta^2=0,006$) and Team B ($F_{(1,48224)} = 2087,341$, $p<0,001$, $\eta^2=0,041$) when defending in the second condition compared to the first condition.

Magnitude and structure of synchrony

Our data also revealed that in the first condition, Team A displayed a lower magnitude of variation (SD) value in the lateral direction of the field compared to the longitudinal direction. However, they exhibited greater regularity (SampEn) in the longitudinal direction in both attacking and defending game phases. Team B displayed a lower magnitude of variation and greater regularity in the longitudinal direction, compared to the lateral direction of the field, in both attacking and defending phases. In the second condition, we verified a lower magnitude of variation and greater regularity in the lateral direction of the field compared to the longitudinal plane for both teams, in attacking and defending phases.

Thus, when comparing values of the magnitude of variation and regularity between game conditions we observed greater stability in the longitudinal direction of the field in the first condition (although Team A presented lower SD values in the lateral direction). The second condition presented more stability in the lateral direction of the field for both teams, and in both attacking and defending game phases.

Please insert Figure 3 near here

Figure 3**.** Example of the time-series representing the P-S synchronisation for both teams using the cluster amplitude, as a function of field direction and game condition. Cluster amplitude values range from 0 (no synchrony) to 1 (complete synchrony). Left and right panels display values for the first and second condition, respectively. Upper and bottom panels display values for the lateral and longitudinal direction, respectively.

Discussion

To the best of our knowledge, this is the first study that sought to investigate synchronisation processes emerging at a micro-to-meso (P-S) level of analysis. To fulfil this purpose, the multilevel hypernetworks approach along with the cluster phase method, previously used in the study of Duarte et al. (2013), was applied to capture the P-S synchronies formed within and between competing players. The results obtained in this study support our hypotheses. Indeed, we observed that local synchronisation tendencies changed when the number, location and size of goals were altered between game conditions, and as a function of ball-possession, field direction and teams. This is particularly interesting, as previous studies (e.g., Duarte et al., 2013; Pinto, 2014) have reported that synchrony does not change as a function of ball possession.

However, a study by López-Felip et al. (2018) identified changes in team synchrony according to ball possession. The results of that study reported higher mean values of team synchrony in defensive sub-phases of play.

However, it is worth mentioning that our study analysed differences in ball-possession according to game conditions, and not between attacking and defending phases. Moreover, a common finding reported in the current literature (e.g., Bourbousson et al., 2010; Duarte et al., 2012a; Duarte et al., 2012b) is that longitudinal displacements present higher levels of synchrony than lateral displacements. Indeed, typical displacements of players on field tend to unfold more frequently in the longitudinal direction of the field, as the attacking team advances upfield seeking to create goal-scoring opportunities. Simultaneously the defending team moves backward trying to prevent the opposing team from creating goal-scoring opportunities in the critical scoring region of the field (Frencken et al., 2011). Both the location of goals and the offside rule has been proposed as two plausible reasons for explaining such results (e.g., Duarte et al., 2012b; Travassos et al., 2012).

It is worth noting that, unlike analyses reported in previous studies of performance in 11-a-side football matches, in the current study the two game conditions consisted of conditioned matches with manipulations of the number, location and size of goals, which did not consider the effects of the offside rule. By not considering the offside rule players were given the opportunity to freely explore the space left behind the opponent’s defensive line whenever they wanted. This task constraint led teams to explore more in-depth attacking movements with- and without ball-possession, in the longitudinal direction of the field when performing in the first condition. Travassos et al. (2014) observed that teams reduced their distances to each other (evaluated through measurement of teams' centroids) when the number of goal targets were manipulated (from two official goals to six mini-goals). The absence of a goalkeeper, in combination with an increased number of possibilities for scoring (due to increased number of goals/targets), possibly led teams to utilise affordances for more forward-backward movements on field (Araújo & Davids, 2016, after Gibson, 1979). The attacking team tried to perform more long passes to get behind the opposition's defence, thus exploiting the absence of the offside law. The defending team tried to prevent this behaviour by reducing distances (approaching defending lines) to the attacking team in the longitudinal direction of the field, seeking to pressurise opponents, while not conceding suitable passing and/or shooting opportunities.

In the second condition, the location of goals at the centre of the field might have constrained players without ball-possession to tightly defend the centre corridor of the field. This tactical approach offered behavioural invitations for the attacking team to circulate the ball to both left and right-hand sides of the pitch (outside riskier zones), thus increasing chances for the defensive team to recover ball-possession. By passing the ball from one side of the field to the other, the movements of the attacking players were designed to pull the defenders away from the central corridor of the field. In fact, maintaining ball-possession, when the team is on the attack, is key to creating goal-scoring opportunities (Garganta, 1997; Guilherme, 2004). Moreover, these actions are grounded on a set of tactical principles of play and/or strategical rules that guide players' actions during competitive performance (Garganta, 1997; Guilherme, 2004). This approach caused the opposing team to stretch on field and created possible empty spaces left between defenders to exploit. Such synergetic, collective movements, manifested by both attacking and defending teams might have increased the synchronisation tendencies in the lateral direction of the field.

However, like the study of Duarte et al. (2013), the differences reported in the current investigation revealed small effect sizes, suggesting the need for further empirical clarification. Nonetheless, these results suggested how players needed to continually reorganise and adjust their functional behavioural patterns (re-organisation of team synergies) to surrounding informational constraints (number, location and size of goals). These constant adaptations produced goal-oriented behaviours coherent with the fulfilment of performance goals (Bernstein, 1967; Davids, 2015). These results imply the sensitivity of inherent synergy formation tendencies to changing performance constraints (Riley et al., 2012), with players temporarily (re)assembling into collective synergies to achieve specific task goals (Silva et al., 2013).

By participating in two conditioned competitive matches with different performance objectives, the participants needed to engage in exploratory behaviours to search for functional movement solutions aiming to satisfy the changing task demands (Davids et al., 2012). They needed to co-adapt their behaviours to changing performance constraints to attain competitive goals (Passos et al., 2016; Passos et al., 2009). The emergence of different behavioural solutions, as evidenced in both game conditions, may signify, for example, that previous preferred coordination tendencies, i.e., higher synchronisation levels verified in the longitudinal direction of the field in the first condition, may no longer have been functional under the constraints of the second condition.

In the first condition, Team B exhibited lower values of SD and SampEn in the longitudinal direction of the field compared to the lateral direction in both game phases. This finding suggested that players displayed greater stability in their coordination tendencies in the simplices with which they interacted in the longitudinal direction of the field. However, Team A showed slightly higher values of SD and lower values of SampEn in the longitudinal, rather than lateral direction of the field in both game phases. In the second condition, we observed lower values of SD and SampEn for both teams in the lateral field direction than longitudinally in both attacking and defending phases. This finding signified that players coordinated their actions in a more regular and stable phase with reference to the simplices they were involved with in the lateral direction of the field.

Conclusions and practical applications

The multilevel hypernetworks approach, along with a CPM, successfully captured the synchronisation processes emerging at a meso-level scale through measurement of P-S synchronies. Nevertheless, this study has some limitations. First, this analysis was typically focused on the "phase" of synchonisation tendencies, when the trajectory of a dynamical system (for example describing coordination in team sports) is a combination of "phase and amplitude". In this way, a movement in a different direction with a different velocity, produced as a consequence of a movement of another player, cannot be quantified as a synchronized behaviour just using the ‘phase’ characteristic, when it is indeed a "coordinated" motion. Thus, in future studies, there is a need to ascertain whether it is more adequate to consider players as “oscillators” (whose phase is adjusted) instead of vectors (whose direction is adjusted). Furthermore, the results are constrained by the specific rules of the game designed by coaches, which could lead to the emergence of diverse results regarding the levels of synchronization inthe longitudinal and lateral directions.

Regardless, the preliminary findings of this study suggested how task constraints manipulations during practice, exemplified here by the number, location and size of target goals, can influence the local synchronisation processes of competing teams. Therefore, coaches may consider these manipulations in their training settings to foment the development of specified local synchronisation tendencies. Here this practical implication was exemplified by how specific sub-groups of players synchronised their movements, longitudinally and/or laterally, during specific sub-phases of play (e.g., defending phase), to recover ball possession. Multilevel hypernetworks seem to constitute a set of suitable and promising tools for measuring the meso-local synchronisation processes emerging in teams during competition.

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