Practice effects on intra-team synergies in football teams

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Abstract

Developing synchronised player movements for fluent competitive match play is a common goal for coaches of team games. An ecological dynamics approach advocates that intra-team synchronization is governed by locally created information, which specifies shared affordances responsible for synergy formation. To verify this claim we evaluated coordination tendencies in two newly-formed teams of recreational players during association football practice games, weekly, for fifteen weeks (thirteen matches). We investigated practice effects on two central features of synergies in sports teams – dimensional compression and reciprocal compensation here captured through near in-phase modes of coordination and time delays between coupled players during forward and backwards movements on field while attacking and defending. Results verified that synergies were formed and dissolved rapidly as a result of the dynamic creation of informational properties, as shared affordances between performers. Practising once a week led to small improvements in the readjustment delays between co-positioning team members, enabling faster regulation of coordinated team actions. Mean values of the number of player and team synergies displayed only limited improvements, possibly due to the timescales of practice. No relationship between improvements in dimensional compression and reciprocal compensation were found for number of shots, amount of ball possession and number of ball recoveries made. Findings open up new perspectives for monitoring team coordination processes in sport.

Keywords: team coordination; shared affordances; dimensional compression; reciprocal compensation.

1. Introduction

In team games, like association football, the rhythmic movements of players forward and backwards on field (MFB) in competing teams represent the patterns formed when attacking and defending. Such movements occur fundamentally in the goal-to-goal direction and have been previously described in analyses of small-sided games (e.g., (Frencken, Lemmink, Delleman, & Visscher, 2011)) and regular football 11-a-side competitive fixtures (e.g., (Frencken, De Poel, Visscher, & Lemmink, 2012; Lames, Ertmer, & Walter, 2010)).

In the coaching literature it is advocated that rhythmic and coordinated movements of players on a team (i.e., advancing up-field to attack and moving back to protect the goal and defend) require coordinated movements of performers to support the necessary team cohesion to outperform opponents (Bangsbo & Peitersen, 2002, 2004; Hughes, 1994; Worthington, 1974). Evidence for this assumption is exemplified by data from the study of Duarte, Araújo, et al. (2013) where large synergistic relations in professional football teams were observed (through cluster phase measures), mainly in the longitudinal direction of the field.

Synergies are temporary assemblages of components constrained to behave as a single functional unit (Kelso, 2012; Riley, Shockley, & Orden, 2012) through the formation of compensatory low-dimensional relations (Kelso, 2009) that continuously emerge and change in complex systems using inherent self-organization processes (Kelso, 1995, 2012). The notion of a synergy has existed in the human movement sciences for over a century (M. Latash, Scholz, & Schöner, 2007), most commonly associated with the problem of coordination by the central nervous system of redundant motor system degrees of freedom to regulate functional movement behaviours (Bernstein, 1967). The formation of synergies between parts of the body during goal achievement

(Davids, Button, Araújo, Renshaw, & Hristovski, 2006; Kelso, 1998) has been considered to lead to a reduction in system dimensionality by harnessing degrees of freedom that are specific to a particular task, while abandoning nonessential ones (Beek, Jacobs, Daffertshofer, & Huys, 2003).

Coordination between players in a sports team displays the same hallmark properties of within-individual movement control by involving the continuous (re) organization and reduction of a team's degrees of freedom (i.e., the numerous movement and action possibilities of individual players) when attacking and defending together (Davids, 2015; Riley et al., 2012). This process is termed dimensional compression and refers to the coupling of independent degrees of freedom of players so that a synergy possesses a lower dimensionality (Fau, Kelso, Saltzman, & Schoner, 1987). Synergy formation processes can be depicted in match play during a team's MFB rhythmic movements where teammates try to move synchronously in space and time in order to maintain team cohesion in achieving performance goals. To do so, they must discard other movement possibilities that do not support this team behaviour at specific moments during performance (e.g., running back towards a team's own goal line when the other teammates are strategically running forward to support an attack). Reciprocal compensation is another important property of a synergy and refers to the ability to compensate for any perturbations to one system component by adjustment in remotely linked parts to preserve its functional integrity (Kelso, 2012; M. L. Latash, Scholz, & Schoner, 2002; Riley et al., 2012). In other words, each component of a synergy possesses the ability to react to changes in others (Riley, Richardson, Shockley, & Ramenzoni, 2011). For instance, during a fast break attack, the movements of attackers towards the opposition goal may leave gaps in remaining team sectors that can be compensated by teammates readjusting their movement direction and speed to link up with the forwards.

1.1 The role of shared affordances in guiding the formation of team synergies

An important related concept in explanations of synergy formation in team sports is the concept of *affordance*. An important conceptualisation of affordances views them as information sources in a performance environment, which may be directly perceived in inviting specific actions from individuals (Gibson, 1979; Turvey, 1992). Information is perceived as opportunities for action and emerges from the continuous interactions of an athlete with key features of a performance environment studied at the ecological scale of analysis (Araújo, Davids, & Hristovski, 2006; Fajen, Riley, & Turvey, 2008). Humans can perceive affordances for themselves and also for other individuals to intentionally regulate behaviours so that cooperative actions eliminate the unnecessary degrees of freedom (i.e., other affordances) to achieve a common intended goal (Mark, 2007; Marsh, Richardson, & Baron, 2006; Stoffregen, Gorday, & Sheng, 1999). As mentioned earlier, perceiving the possibility to move towards the opposition goal also implies perceiving the same possibilities and intentions in teammates so that team cohesiveness can be maintained. According to Gibson (1979) *"behaviour affords behaviour (p. 135)"* signifying how coordination tendencies between team players may emerge through shared affordances during competitive performance. Thus, synergies are formed on a platform of a shared (mainly visual and non-verbal) communication channels used by teammates to collectively perceive affordances for interactive behaviours (Passos, Cordovil, Fernandes, & Barreiros, 2012; Silva, Garganta, Araújo, Davids, & Aguiar, 2013). Shared affordances are crucial in synergy formation because they enable dimensional compression and reciprocal compensation by reducing the number of independent degrees of freedom (i.e., the multitude of coordinating options for players) and supporting fast compensatory actions (i.e., allowing players to respond to each other's actions in order to ensure the attainment of team goals) (Araújo, Silva, & Davids, 2015; Araújo, Silva, & Ramos, 2014; Riley et al., 2011; Silva et al., 2013). In football teams this process is predicated, for example, on the multitude of coupled movement behaviours between teammates resulting in reduced times from their co-positioning during attacking and defending team movements.

1.2 Current understanding of synergies in team sports

Many researchers have claimed that synergies (also commonly referred as couplings) form the basis of interpersonal coordination in team sports (e.g., (Duarte, Araújo, Correia, & Davids, 2012; McGarry, Anderson, Wallace, Hughes, & Franks, 2002; Silva et al., 2013). These claims justify the pertinence and need for studies addressing the emergence of intra-team synergies in team sports like association football. Most of the existing studies ion team coordination processes have focused attention on the degree of movement coordination in dyads or sub-groups of players in team sports like football. To this effect, relative phase (Palut & Zanone, 2005), running correlations (Corbetta & Thelen, 1996) and cluster phase (Richardson, Garcia, Frank, Gergor, & Marsh, 2012) analyses have played an important measurement role. Important findings about team coordination have been derived from such quantities. For instance, it has been shown that different coordination tendencies may be displayed in team players by adoption of different strategies according to the level of opposition faced (Folgado, Duarte, Fernandes, & Sampaio, 2014) and defensive playing strategies adopted (man-to-man vs. zone defence) (Duarte, Travassos, Araújo, & Richardson, 2013).

Other studies have analysed lower dimensional variables (e.g., team centroid and team dispersion measures like the stretch index) that have captured team collective behaviours. Clemente, Couceiro, Martins, Mendes, and Figueiredo (2013), for instance, found pronounced oscillations of both teams' centroids in a lateral direction, interpreted as efforts by the team with the ball to destabilize the defensive organization of opponents by changing the flank of attack. In another study, Yue, Broich, Seifriz, and Mester (2008) have highlighted the dynamics of attacking and defending in football by representing the intermittent expansion and contraction patterns of competing teams.

Despite the relevance of the aforementioned work, to the best of our knowledge, the structural features of synergies like dimensional compression and reciprocal compensation have yet to be investigated in team sports. Previous studies have mostly studied team collective behaviours (e.g., a team's relative position on-field and its expansion and contraction patterns) and the strength of synergies formed (e.g., the relative phase and cluster phase degree of coordination), but not the reduction of the players' degrees of freedom, nor their compensatory actions. Understanding how such important features occur may develop our understanding oft team coordination processes and provide new insights for improving team performance.

There is also a lack of research addressing effects of practice on intra-team synergy formation. If synergies form the basis of team performance it is plausible to expect that couplings between players could also be susceptible to improvement. Relatedly, it is unknown whether increases in the number of synergies formed between teammates can constrain efficacy of attacking and defending. Considering that teammates share the same objectives (McGarry et al., 2002), hypothetically, the establishment of stronger synergies would lead to higher levels of team coordination impacting positively on team performance indicators typically associated with success, like the number of shots at goal (Lago, Ballesteros, Dellal, & Gómez, 2010; Szwarc, 2007) percentage of ball possession (Lago & Dellal, 2010) in attack, and the number of ball recoveries in defence (Almeida, Ferreira, & Volossovitch, 2014).

In this study we sought to describe the processes of dimensional compression and reciprocal compensation of intra-team synergies within newly-formed football teams and to verify whether the number of stronger couplings between players (here interpreted as stronger synergies) could be improved with practice and associated with successful performance. We hypothesized that the number of strong synergies (i.e., through dimensional compression) emerging during coordinated team movements would increase with practice and enable fast co-positioning movements between teammates (i.e., faster reciprocal compensations of players), possibly supporting more functionally efficient attacking behaviours (here defined as greater ball possession and more shots) and defensive actions (defined as more ball recoveries).

2. Methods

2.1 Participants

Twenty-nine undergraduate students from the Faculty of Sports of Porto University were recruited to participate in this study (mean ± standard deviation – age: 20.21±1.74 yrs; height: 178.07±5.87 cm; weight: 73.52±7.47 kg). Participants were enrolled in football classes for 2 hours, once a week for fifteen weeks, as part of their curricula on a Sports Science degree.

Participants' previous experiences in football practices were varied, ranging from 0 to 15 years (6.14±4.95 yrs). Ten students in our sample had never participated in structured football practices or competitive fixtures. At most, they had only participated in such activities for a maximum period of three years in early childhood. The remaining nineteen students had experience levels ranging from 4 to 15 years, comprising football practice and competition, with seven students still playing at a senior amateur level, outside faculty classes.

The study was approved by the local Ethics Committee. All participants provided their informed consent before taking part in the study.

2.2 Experimental design

In the first football class students were assembled into two technically equivalent teams that played under two different formations (team A: 1-4-3-3; team B: 1-4-4-2). Teams A and B were composed of eleven players plus five and four reserves, respectively. An accredited UEFA-B level teacher, possessing ten years of experience in teaching and coaching youth players at club and high-school levels, coordinated the football classes. The constitution of both teams and the assignment of positional roles to players was based on: (i) previous experiential knowledge of the teacher about the students' skills obtained during football classes in the previous semester[1], (ii) participants' previous experience in football practices and competitive fixtures,

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[1] The program in the 1st semester comprised reduced numbers in game formats typically used in youth football developmental programs (5-a-side and 7-a-side), whereas the 2nd semester classes addressed the structural organization of regular 11-a-side football teams.

outside faculty classes, (iii) preferred positional roles and (iv) preferred foot. The goalkeepers in the sample volunteered to assume the role as they played in that position in clubs at a regional-level outside football classes. All classes included practical activity delivered within a game-centred approach (Gabbett, Jenkins, & Abernethy, 2009), involving the practice of small-sided games to address current football offensive and defensive strategies. The fundamental course aim was to educate students in the theoretical content of sports science sub-disciplines composing the course curricula. Participant understanding of football tactics was also often stimulated through questioning and reflection during classes and, thus, training exercises were interspersed with large instructional periods that allowed participants to recover between exercise bouts. After this initial period (of approximately 50 minutes duration) participants played regular 11v11 matches divided into two halves of fifteen minutes, separated by seven minutes of passive recovery and rehydration. These matches formed an internal class tournament, where points were allocated to winning teams throughout the semester. Additional points were also given for the team that performed more ball recoveries in their offensive midfield and more shots on target (independently of the final result) to stimulate an attacking style of play and avoid the adoption of distinct playing strategies according to the match status throughout the tournament (Almeida et al., 2014; Lago, 2009).

Students were allowed to change their positional role when performing in the first part of the class, but not during the tournament matches undertaken at the end of the class.

2.3 Data collection

During each match, each player carried an unobtrusive global positioning tracking device (GPS) that captured the longitudinal and latitudinal movement coordinate time-series with a sampling frequency of 10 Hz (Qstarz, model: BT-Q1000eX). Trajectories of each player were calculated using positional data from GPS devices. Longitudinal and latitudinal (spherical) coordinates were converted to Euclidean (planar) coordinates using the Haversine formula (Sinnott, 1984). The field was calibrated with the coordinates of four GPS devices stationed in each corner, and the origin of the Cartesian coordinate system was placed at the pitch centre. Fluctuations in player positioning were reduced using a moving average filter with a time scale of 0.2 seconds and data resampling was employed to synchronise the time series of all players within each game. MatLab R2013b (The Mathworks, USA) was used to process and analyse the data.

In each match, each team was monitored for fifteen minutes of match play (team A was monitored for the first half and team B in the second half) throughout the period of fifteen weeks. A total of thirteen matches were performed and GPS data were available and analysed for twelve matches[2].

2.4 Variables

Synergy formation between teammates during the MFB of competition was analysed by, first, calculating the radial distance of each player to their goal centre, over time.

[2] At weeks 8 and 11, classes did not take place due to a national public holyday and an academic event, respectively. At week 3 the final match class was not recorded with the GPS system due to severe rain that altered turf conditions, affecting participants' movements and ball bounce.

No differentiation for the players' lateral and longitudinal movements was undertaken given that the natural rhythmic flow of a competitive game typically unfolds in the longitudinal direction (i.e., goal-to-goal) (Folgado, Duarte, Marques, & Sampaio, 2015; Frencken et al., 2012), and also because two players can enter in coordination modes by distancing themselves from their goal laterally and longitudinally (e.g., the coordinated movements of the full back who moves laterally to create space and receive the ball during build up with the movements of the winger who runs deep to receive a long pass from him – in both cases, players are coordinating by distancing themselves from their goal, one dominantly through lateral movements and the other through longitudinal movements).

The distance to the goal was used as a reference because it has been previously proposed that proximity to the goal exerts an influence on interpersonal coordination tendencies between opposing (Headrick et al. (2012) and cooperating players (Travassos, Araújo, Duarte, & McGarry, 2012; Travassos, Gonçalves, Marcelino, Monteiro, & Sampaio, 2014). Thus, players' co-positioning movements towards and way from their own goal are constrained by their relative positioning on field at any given instant. The couplings that emerged between teammates (Pc) during such movements were taken to depict the number of synergies established by each player during attacking and defending patterns of play. This quantity represented the necessary reduction in the players' movement coordination possibilities and, thus, depicted the dimensional compression of synergies at the individual-level. Players' couplings with teammates were considered to represent the establishment of synergies (as they share the same goals) and were assessed by calculating the relative phase of all pairs (defined as two teammates co-positioning relative to each other) for distances to their own goal over time using a Hilbert transform (Palut & Zanone, 2005). The radial distance of players to the goal described the stationary near-sinusoidal time series (see Figure 1A) highlighting the cyclical nature of a football match. A relative phase value between -30º to 30º (near-in-phase synchronisation mode) was considered to represent a strong coupling between a dyad of cooperating players (i.e., a synergy), as previously used in other studies (e.g., Folgado et al. (2014)). Then, for each outfield player it was recorded the number of teammates with whom they formed strong couplings (out of a maximum of 9; couplings with the goalkeeper were excluded) for each time frame (i.e., ten times per second). Furthermore, it was noted the total number of couplings between teammates in each team (out of a maximum of 45 possible couplings) in each time frame. Team couplings (Tc) provided information on the number of synergies formed within a team that momentarily supported their collective MFB between attack and defence. They were interpreted as a measure of dimensional compression at a team level. An example of the formation of Pc and Tc during a 6-second movement forward by an attacking team is illustrated in Figure 1B.

(Figure 1 near here)

The players' co-positioning delay (Rd) to adjust to teammates' movements was computed as a measure of reciprocal compensation and synchronization speed during attacking and defending patterns of play. Lower delay values indicate rapid compensation of movements and faster spatial-temporal synchrony between players, whereas a larger readjustment delay might impede spatial-temporal synchrony of player movements. To analyse Rd, the time series of distances to goal of each dyad were lagged in time, relative to one another, for maximal agreement, reported through the highest correlation coefficient values. A windowed cross-correlation technique, with overlapping time windows that covered the whole time series (see Figure 2a for an illustration of this technique) data was then used for each player with all his nine teammates, producing a moving estimate of association and lag (Boker, Xu, Rotondo, & King, 2002). The max lags (i.e., the lags registering the highest absolute *r*-values) were considered to represent the time delay, in seconds, between two players' co-positioning in relation to their own goal (see Figure 2b for an illustration of a delay between two teammates). The average duration of a playing sequence throughout matches ranged between 9 to 13 seconds, for both teams. Thus, a minimum window size of 20 s (200 data points) was chosen as an appropriate time window to scrutinise the coupling strength between two teammates. During such periods the probability of encompassing both attacking and defending movements was higher. A maximum lag range of 10 seconds (100 data points) was chosen based on the experiential knowledge of a panel of five youth coaches (coaching experience: 11.6±3.9 years in youth Football). They proposed a value for the maximum delay that could hypothetically occur between the movements of two players during a match (agreed independent of the teams disputing ball possession). Max lags differing from zero were considered to be positive lags, independent of the player that was temporally leading the competitive interactions. Through this process, it was generated, for each player, a matrix composed of nine time series with length of match duration, containing the Rd with his nine teammates (goalkeepers excluded).

Finally, performance indicators including the total number of shots, percentage of ball possession and number of direct ball recoveries (tackles and interceptions) were recorded for each team in each match using a hand notation system (inter and intra-observer reliability: Kappa > 0.95 for all performance indicators).

Computation of all variables was processed in Matlab R2011a (Mathworks, USA).

2.5 Data analysis

Descriptive statistics were performed to quantitatively describe the central tendencies (mean) and dispersion (standard deviation) of Pc and Tc during matches across time. For each player, the Rd matrix was organized, time-frame by time-frame, according to each dyad's coupling strength (i.e., from the strongest to the weakest coupling, following relative phase values). A least squares line was fitted to the Pc, Tc and Rd data and slopes were measured to describe the coupling tendencies, whereas the associated coefficients of determination (R^2) were interpreted as an effect size of practice on dimensional compression (Pc and Tc) and reciprocal compensation (Rd) of synergies formed.

Data on frequencies of shots, ball recoveries and percentage of ball possession were displayed for each match. All periods of game stoppages (i.e., ball out, fouls, etc.) were excluded from analyses (percentage of ball possession was assessed as a proportion of actual playing time).

3. Results

Figure 3 depicts some features of the dynamics of emergent couplings (i.e., synergies) formed between players during the MFB of team A during fifteen minutes of match play (match 13, week 15). Players were, on average, coupled with six teammates (6.3±2.55) during their team's MFB and oscillations in the number of couplings occurred in a similar fashion for all players (Figure 3-A). In this example the average team couplings (Tc) was approximately 32 (31.51±10.62), with values oscillating between 10 and 45 team couplings (Figure 3-B).

Mean Pc and Tc increased and decreased with no discernible pattern, evidencing only slight improvements with practice over the weeks, here depicted by small positive slopes and very small values of R^2 for both teams (Figures 3-C and 3-D, respectively). Pc mean values for both teams ranged between 4 to 6 couplings whereas Tc mean values situated in between 22 to 33 couplings across the program.

(Figure 3 near here)

Figure 4 shows that Rd values were lower for co-positioning between most coupled teammates, as expected. It is also clear that players in both teams decreased the delays between their co-positioning movements from the first to the last match. At week 1, only the first and second most coupled teammates of each player responded to each other's movements within the range of approximately one second in team A. Team B displayed even larger values of Rd for each player to their 1st and 2nd most coupled teammates. This value increased markedly from the third to the ninth most coupled teammate on both teams. Thirteen practice games later, the first seven most coupled teammates responded to each other's movements within the range of approximately one second, in both teams. Team B showed a larger Rd reduction from week 1 to week 15.

(Figure 4 near here)

When describing the effects of practice across time, both teams have decreased the co-positioning delays to their teammates (Figure 5). In general, regression values (R^2) are low for team A and moderate for team B, independently of coupling strength. The slopes are consistent in sign (always negative) and in amplitude, highlighting a slight decreasing tendency in Rd across weeks. This was not a straightforward process, as teams displayed random variations across matches. A decreasing trend was more evident for team B that showed larger R^2 values, especially for the least synchronised teammates (from the 5th to the 9th most synchronised teammates).

(Figure 5 near here)

Team tactics (1-4-3-3 or 1-4-4-2), performance indicators like percentage of ball possession, shots and ball recoveries (see Figure 6) and regularity of players in team formation (i.e., playing with the same players on repeated positions, see Table in Appendix) were not clearly associated with mean values of Pc and Tc. For instance, in match 6, team A presented the largest mean values of Pc and Tc. However, they achieved the same number of shots, more ball recoveries and a higher percentage of ball possession in match 8, where they registered one of the lowest mean values of Pc and Tc (see Figures 6A and 6C). The same happened for team B in matches 10 and 12, for example (see Figures 6B and 6D).
However, Rd seemed to be lower for larger values of Pc and Tc and vice-versa. For example, in match 8, team A displayed the lowest value of Pc (4.28±2.54) and Tc (21.42±10.29) and the largest values of Rd (first to last most coupled teammates mean Rd: 1.12 – 3 seconds). Team B showed the lowest values of Rd on match 10 (first to last most coupled teammates mean Rd: 0.95 – 1.8 seconds) where they displayed the largest mean values of Pc (6.6±2.44) and Tc (32.98±10.46).

(Figure 6 near here)

4. Discussion

The main aim of this study was to characterise the processes of dimensional compression and reciprocal compensation of intra-team synergies formed during the rhythmic movements forward and backwards (MFB) of attacking and defending in football teams. The study also aimed to verify how practice impacted on the formation of player and team synergies with respect to these two features and their repercussions on team performance during attacking and defending phases of play. Results showed that synergies emerged and dissolved very quickly throughout a match, oscillating between peaks where players synchronised movements with 8-9 teammates, dropping to 2, 1 or even 0 teammates a few seconds later. This oscillating process probably corresponded to moments where teams had to readjust to new functions like, for example, switching from a backwards move during defending to a fast forward move after regaining ball possession. This assumption needs further verification, since a decrease in the number and magnitude of drops in Pc might be associated with higher team cohesiveness during match transitions.

This oscillating property of synergy formation stresses the idea that moving players provide informational properties that offer or invite actions, changing over different timescales, as shared affordances between team members (Silva et al., 2013). Switching from 9 to 0 couplings and then forming 8 – 9 couplings in a matter of seconds defines a typical process of team synchrony-asynchrony-synchrony, where players need to perceive momentarily each other's affordances and intentions (Passos et al., 2012; Silva et al., 2014) and rapidly readjust their behaviours accordingly, whenever a perturbation to team synchrony occurs (e.g., losing ball possession). It is plausible to consider that this observation highlights the dimensional compression feature of synergies in sports teams, guided by informational constraints that shape the perception of shared affordances available for players (Araújo et al., 2014). As some players advanced up-field, other players were compelled to follow in corresponding to team patterns of play (see Figure 1). It is worth speculating that these team behaviours may have been underpinned by shared affordances and intentions that link players by reducing their number of action possibilities (Silva et al., 2013).

Another interesting property found was that all Pc values tended to follow an identical dynamical structure over time. That is, players tended to increase and decrease their number of couplings, simultaneously, highlighting a coordinated search for synchrony and ultimately shaping a similar Tc behaviour. Similar findings were reported by Duarte, Araújo, et al. (2013) that observed near in-phase modes of coordination for player-team synchrony with individual actions being tightly coordinated with team behaviours during players' movements on field.

Mean values of Pc and Tc showed only a slight increase with practice over time. This finding opens up the question of how couplings between players might vary in higher-level teams engaged in more extended and regular practice programs, justifying the need for further studies. Nonetheless, Rd values of both teams decreased, in general, over the weeks (specially for team B), evidencing faster readjustments of coupled players during the rhythmic flow of matches (particularly the Rd value of each player's least coupled teammates). This process may refer to the reciprocal compensation property of synergies (Kelso, 2012; M. L. Latash et al., 2002; Riley et al., 2012), translated into the players' ability to react to movements of each other. Given the results of this study, this synergy property seems to be one that most improved with practice or, at least, the one that primarily benefited from practising in earlier stages of training. Further studies are necessary to verify this claim.

A larger number of couplings seemed also to be associated with faster readjustment movements of players (i.e., improved reciprocal compensation). This should be expected given that a synergistic organization serves a functional role in adapting to task constraints (i.e., ultrafast regulation of actions; Riley et al., 2011), here depicted by faster readjustment between players. The proposal of an affordance-based coordination supports this view, given that practice can attune players to relevant informational sources (i.e., relevant shared affordances), such as action possibilities for other team members (Ramenzoni, Davis, Riley, & Shockley, 2010; Ramenzoni, Riley, Davis, Shockley, & Armstrong, 2008) and their intentions (Runeson & Frykholm, 1981; Runeson & Frykholm, 1983).

The small decrease in Rd found for both teams might have been due to the limited amount of practice time that participants experienced. Effects of systematic practice on players of higher skill levels should be further tested. Other possible sources of noise in the data might be due to: (i) the distance-to-own goal variable being insensitive to lateral movements away from the goal; (ii) participants performing other sporting activities outside classes, which could not be controlled, (iii) the possibility that some participants had very limited amounts of previous experience in football; and (iv), the accumulation of fatigue and lack of conditioning which could have impaired participant tactical performance during tournament matches. Independently, both teams seemed to acquire faster regulating movements after the program (specially team B). These findings concurred with data reported by Sampaio and Maçãs (2012) who found improvements in coordination tendencies of football teams composed of undergraduate Sports Sciences students enrolled in similar amounts of practice (2 hours per week for 13 weeks). In their study (using 5v5 games), participants displayed more regular oscillating distances to their teams' centres and improved anti-phase patterns in most team dyads, showing that the players' movements became more coordinated with increasing expertise.

Higher frequencies of shots, ball recoveries, goals and percentage of ball possession were not necessarily associated with higher values of Pc and Tc and reduced Rd. Possibly because both teams were receiving the same treatment and thus, equally improving their performance simultaneously. Further studies should be conducted using a control group. However, in the present research only mean values of Pc, Tc and Rd were analysed, thus, the possibility of such match events being associated with specific periods, where larger numbers of strong synergies are exclusively formed, should not be excluded. In this sense, it is suggested that future work should try to relate the temporal structure of these variables with the observations of successful attacking and defending performance.

5. Conclusions

Moving synchronously on field is a behaviour that most coaches seek to establish in team games. Here, we have demonstrated that such team movements are grounded on the formation of synergies, responsible for linking actions of teammates during synchronized rhythmic movements forward and backwards on field during attacking and defending phases of play.

The dimensional compression and reciprocal compensation features of synergies have been shown to improve with practice, specially the former. A *shared-affordances* based rationale was presented, advocating that players became faster at regulating their movements with teammates by learning to perceive affordances for each other.

This occurred with just two hours of practice per week in a sample of relatively inexperienced undergraduate sports sciences students.

These findings open up new perspectives for the study of coordination processes in sports teams. The couplings supporting synchronised and fast regulating team movements in professional athletes should be further analysed and tested as potential variables to monitor performance improvements over time. Another important issue relates to the fact that, many times, asymmetric movement may represent a specific strategic type of synergy (e.g., two players exchanging positions to avoid close marking from opponents), which should also be accounted for in future research. The possibility of such variables being reliable predictors of successful team actions should not be discarded. Thus, future research should aim to match specific performance events (e.g., goals, shots, tackles, etc.) with the dynamic structure of synergy formation.

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7. References

Almeida, C. H., Ferreira, A. P., & Volossovitch, A. (2014). Effects of Match Location, Match Status and Quality of Opposition on Regaining Possession in UEFA Champions League. *Journal of Human Kinetics, 41*, 203-214. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=96863336&lang=pt-br&site=ehost-live
http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4120454/pdf/jhk-41-203.pdf

Araújo, D., Davids, K., & Hristovski, R. (2006). The ecological dynamics of decision making in sport. *Psychology of Sport and Exercise, 7*, 653-676.

Araújo, D., Silva, P., & Davids, K. (2015). Capturing group tactical behaviors in expert team players. In J. Baker & D. Farrow (Eds.), *Routledge Handbook of Sport Expertise* (pp. 209-220): Routledge.

Araújo, D., Silva, P., & Ramos, J. P. (2014). Affordance-based decisions guide team synergies during match performance. *Research in Physical Education, Sport and Health, 3*(1), 19-26.

Bangsbo, J., & Peitersen, B. (2002). *Defensive soccer tactics*. Leeds: Human Kinetics.

Bangsbo, J., & Peitersen, B. (2004). *Offensive soccer tactics*. Champaign, IL: Human Kinetics.

Beek, P., Jacobs, D., Daffertshofer, A., & Huys, R. (2003). Expert performance in sport: Views from the joint perspectives of echological psychology and dynamical systems theory. In J. Starkes & K. A. Ericsson (Eds.), *Expert performance in sports: Advances in research on sport expertise* (pp. 321-344). Champaign, IL: Human kinetics.

Bernstein, N. (1967). *The coordination and regulation of movements*. Oxford: Pergamon Press.

Boker, S. M., Xu, M., Rotondo, J. L., & King, K. (2002). Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. *Psychological Methods, 7*(3), 338-355. Retrieved from http://psycnet.apa.org/journals/met/7/3/338/

Clemente, F., Couceiro, M., Martins, F., Mendes, R., & Figueiredo, A. (2013). Measuring collective behaviour in football teams: Inspecting the impact of each half of the match on ball possession. *International Journal of Performance Analysis in Sport, 13*, 678-689.

Corbetta, D., & Thelen, E. (1996). The developmental origins of bimanual coordination: a dynamic perspective. *Journal of Experimental Psychology: Human Perception and Performance, 22*(2), 502-522.

Davids, K., Button, C., Araújo, D., Renshaw, I., & Hristovski, R. (2006). Movement models from sports provide representative task constraints for studying adaptive behaviour in human movement studies. *Adaptive Behavior, 14*, 73-94.

Duarte, R., Araújo, D., Correia, V., & Davids, K. (2012). Sport teams as superorganisms: implications of biological models for research and practice in team sports performance analysis. *Sports Medicine, 42*(8), 633-642.

Duarte, R., Araújo, D., Correia, V., Davids, K., Marques, P., & Richardson, M. (2013). Competing together: Assessing the dynamics of team-team and player-team synchrony in professional association football. *Human Movement Science, 32*, 555-566. Retrieved from http://ac.elscdn.com/S0167945713000262/1-s2.0-S0167945713000262-main.pdf?_tid=5178503e-5003-11e4-9e9c-00000aacb35f&acdnat=1412893771_01a0dca5154ac055f7310139344a5d5a

Duarte, R., Travassos, B., Araújo, D., & Richardson, M. (2013). The influence of manipulating the defensive playing method on collective synchrony of football teams. In D. Peters & P. O'Donoghue (Eds.), *Performance Analysis of Sport IX*. London: Routledge, Taylor & Francis Group.

Fajen, B., Riley, M., & Turvey, M. (2008). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology, 40*, 79-107.

Fau, K. B., Kelso, J. A., Saltzman, E. L., & Schoner, G. (1987). Space-time behavior of single and bimanual rhythmical movements: data and limit cycle model. *Journal of Experimental Psychology-Human Perception and Performance, 13*, 178-192.

Folgado, H., Duarte, R., Fernandes, O., & Sampaio, J. (2014). Competing with Lower Level Opponents Decreases Intra-Team Movement Synchronization and Time-Motion Demands during Pre-Season Soccer Matches. *PLoS ONE, 9*(5), e97145. doi:10.1371/journal.pone.0097145

Folgado, H., Duarte, R., Marques, P., & Sampaio, J. (2015). The effects of congested fixtures period on tactical and physical performance in elite football. *Journal of Sports Sciences*, 1-10. doi:10.1080/02640414.2015.1022576

Frencken, W., De Poel, H., Visscher, C., & Lemmink, K. (2012). Variability of inter-team distances associated with match events in elite-standard soccer. *Journal of Sports Sciences, 30*(12), 1207-1213. doi:10.1080/02640414.2012.703783

Frencken, W., Lemmink, K., Delleman, N., & Visscher, C. (2011). Oscillations of centroid position and surface area of soccer teams in small-sided games. *European Journal of Sport Science, 11*(4), 215-223.

Gabbett, T., Jenkins, D., & Abernethy, B. (2009). Game-based training for improving skill and physical fitness in team sport athletes. *International Journal of Sports Science & Coaching, 4*(2), 273-283.

Gibson, J. (1979). *The ecological approach to visual perception*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Headrick, J., Davids, K., Renshaw, I., Araújo, D., Passos, P., & Fernandes, O. (2012). Proximity-to-goal as a constraint on patterns of behaviour in attacker-defender dyads in team games. *Journal of Sports Sciences, 30*(3), 247-253.

Hughes, C. (1994). *The football association coaching book of soccer tactics and skills*. Harpenden: Queen Anne Press.

Keith Davids, D. A., Ludovic Seifert, Dominic Orth. (2015). Expert performance in sport: An ecological dynamics perspective. In J. Baker & D. Farrow (Eds.), *Routledge Handbook of Sport Expertise* (pp. 130-144): Routledge.

Kelso, J. A. S. (1995). *Dynamic patterns: the self-organizing of brain and behavior*. Massachusetts: MIT Press.

Kelso, J. A. S. (1998). From Bernstein's physiology of activity to coordination dynamics. In M. Latash (Ed.), *Progress in motor control. Bernstein's traditions in movement studies* (pp. 203-219). Champaign, IL: Human Kinetics.

Kelso, J. A. S. (2009). Synergies: Atoms of brain and behavior. In D. Sternad (Ed.), *Progress in motor control: A multidisciplinary perspective* (pp. 83-91). New York: Springer.

Kelso, J. A. S. (2012). Multistability and metastability: understanding dynamic coordination in the brain. *Philosophical transactions of the Royal Society B: Biological Sciences, 367,* 906-918.

Lago, C. (2009). The influence of match location, quality of opposition, and match status on possession strategies in professional association football. *Journal of Sports Sciences, 27*(13), 1463 - 1469. Retrieved from http://www.informaworld.com/10.1080/02640410903131681

Lago, C., Ballesteros, J., Dellal, A., & Gómez, M. (2010). Game-related statistics that discriminated winning, drawing and losing teams from the Spanish soccer league. *Journal of Sports Science & Medicine, 9*(2), 288-293. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=52291897&site=ehost-live

Lago, C., & Dellal, A. (2010). Ball possession strategies in elite soccer according to the evolution of the match-score: the influence of situational variables. *Journal of Human Kinetics, 25,* 93-100.

Lames, M., Ertmer, J., & Walter, F. (2010). Oscillations in football - order and disorder in spatial interactions between the two teams. *International Journal of Sport Psychology*(41), 85-86.

Latash, M., Scholz, J., & Schöner, G. (2007). Toward a new theory of motor synergies. *Motor Control, 11,* 276-308.

Latash, M. L., Scholz, J. P., & Schoner, G. (2002). Motor control strategies revealed in the structure of motor variability. *Exercise and Sport Sciences Reviews, 30*, 26-31. Retrieved from http://graphics.tx.ovid.com/ovftpdfs/FPDDNCMCBEIDMI00/fs004/ovft/live/gv006/00003677/00003677-200201000-00006.pdf

Mark, L. S. (2007). Perceiving the Actions of Other People. *Ecological Psychology, 19*(2), 107-136. doi:10.1080/10407410701331967

Marsh, K. L., Richardson, M. J., & Baron, R. M. (2006). Contrasting approaches to perceiving and acting with others. *Ecological Psychology, 18*(1), 1-38.

McGarry, T., Anderson, D., Wallace, S., Hughes, M., & Franks, I. (2002). Sport competition as dynamical self-organizing system. *Journal of Sports Sciences, 20*, 771-781.

Palut, Y., & Zanone, P.-G. (2005). A dynamical analysis of tennis: Concepts and data. *Journal of Sports Sciences, 23*(10), 1021-1032.

Passos, P., Cordovil, R., Fernandes, O., & Barreiros, J. (2012). Perceiving affordances in rugby union. *Journal of Sports Sciences, 30*(11), 1175-1182. Retrieved from http://search.ebscohost.com/login.aspx?direct=true&db=s3h&AN=77874177&lang=pt-br&site=ehost-live
http://www.tandfonline.com/doi/pdf/10.1080/02640414.2012.695082

Ramenzoni, V., Davis, T., Riley, M., & Shockley, K. (2010). Perceiving action boundaries: Learning effects in perceiving maximum jumping-reach affordances. *Attention, Perception, & Psychophysics, 72*(4), 1110-1119.

Ramenzoni, V., Riley, M., Davis, T., Shockley, K., & Armstrong, R. (2008). Tuning in to another person's action capabilities: perceiving maximal jumping-reach height from walking kinematics. *Journal of Experimental Psychology, 34*(4), 919-928.

Richardson, M., Garcia, R., Frank, T., Gergor, M., & Marsh, K. (2012). Measuring group synchrony: a cluster-phase method for analyzing multivariate movement time-series. *Frontiers in Psychology, 3*(Article 405), 1-10.

Riley, M., Richardson, M., Shockley, K., & Ramenzoni, V. (2011). Interpersonal synergies. *Frontiers in Psychology, 2*(38), 1-7.

Riley, M., Shockley, K., & Orden, G. V. (2012). Learning from the body about the mind. *Topics in Cognitive Science, 4*, 21-34.

Runeson, S., & Frykholm, G. (1981). Visual perception of lifted weight. *Journal of Experimental Psychology: Human Perception and Performance, 7*(4), 733-740. doi:10.1037/0096-1523.7.4.733

Runeson, S., & Frykholm, G. (1983). Kinematic specification of dynamics as an informational basis for person-and-action perception: Expectation, gender recognition, and deceptive intention. *Journal of Experimental Psychology: General, 112*(4), 585-615. doi:10.1037/0096-3445.112.4.585

Sampaio, J., & Maçãs, V. (2012). Measuring tactical behaviour in football. *International Journal of Sports Medicine, 33*(5), 395-401. doi:10.1055/s-0031-1301320

Silva, P., Garganta, J., Araújo, D., Davids, K., & Aguiar, P. (2013). Shared knowledge or shared affordances? Insights from an ecological dynamics approach to team coordination in sports. *Sports Medicine, 43*, 765-772. Retrieved from http://download.springer.com/static/pdf/461/art%3A10.1007%2Fs40279-013-

0070-
9.pdf?auth66=1412892961_6cb1ecc479645be745be62c1cb13439d&ext=.pdf

Silva, P., Travassos, B., Vilar, L., Aguiar, P., Davids, K., Araújo, D., & Garganta, J. (2014). Numerical relations and skill level constrain co-adaptive behaviors of agents in sports teams. *PLoS ONE, 9*(9), e107112.

Sinnott, R. W. (1984). Virtues of the Haversine. *Sky and Telescope, 68*(2), 159.

Stoffregen, T., Gorday, K., & Sheng, Y.-Y. (1999). Perceiving affordances for another person's actions. *Journal of Experimental Psychology: Human Perception and Performance, 25*(1), 120-136.

Szwarc, A. (2007). Efficacy of successful and unsuccessful soccer teams taking part in finals of Champions League. *Research Yearbook, 13*(2), 221-225.

Travassos, B., Araújo, D., Duarte, R., & McGarry, T. (2012). Spatiotemporal coordination behaviors in futsal (indoor football) are guided by informational game constraints. *Human Movement Science, 31*(4), 932-945. doi:10.1016/j.humov.2011.10.004

Travassos, B., Gonçalves, B., Marcelino, R., Monteiro, R., & Sampaio, J. (2014). How perceiving additional targets modifies teams' tactical behavior during football small-sided games. *Human Movement Science*, *38*(0), 241-250. doi:http://dx.doi.org/10.1016/j.humov.2014.10.005

Turvey, M. (1992). Affordances and prospective control: an outline to the ontology. *Ecological Psychology, 4*(3), 173-187.

Worthington, E. (1974). *Learning and teaching soccer skills*. Hollywood: Wilshire Book Company.

Yue, Z., Broich, H., Seifriz, F., & Mester, J. (2008). Mathematical analysis of a soccer game. Part I: individual and collective behaviours. *Studies in Applied Mathematics, 121*, 223-243.

Figure Captions

Figure 1 – A) Dynamics of the distance to own goal for all outfield players in a team during fifteen minutes of match play (sampled at 10 Hz). Vertical y-axis represents distance to own goal in meters (m). B) Exemplar representation of one team movement towards the opposition goal and the co-positioning of players to adjust to each other's movements (6-seconds duration). The assembly of synergies is depicted, frame-by-frame, by the couplings (solid black lines) between teammates (relative phase values for their distances to goal in between -30-30º - near in-phase synchronisation mode). The grey dot and solid lines represent the team centre and its distance to the team's own goal. Pc – average number of couplings per player; Tc – total number of established couplings in the team.

Figure 2 – A) the windowed-cross correlation technique (adapted from Boker et al., 2002). In the example provided it is used a sliding time window of 7 data points and a maximum lag range of 1. B) Illustration of a time delay between two players from team B (the right-winger and the fullback) during an attacking move. It is possible to see that the winger starts his movement forward sooner than the fullback.

Figure 3 – A) Dynamics of emergent player couplings during team ebb-and-flow movements for 15 minutes of match play (solid and dashed lines represent means ± standard deviations respectively); B) Dynamics of emergent team couplings during team ebb-and-flow movements for 15 minutes of match play (out of 45 possible couplings); C) and D) Effects of football practice (13 games) on the average player couplings (teams A and B, respectively); E) and F) Effects of football practice on the

average team couplings (teams A and B, respectively). Error bars on C), D), E) and F) represent standard deviation.

Figure 4 – Mean co-positioning delay for each player with teammates during different attacking-defending movement patterns according to the order of coupling strength (from the 1st to the 9th most coupled teammate – weeks 1 and 15). Error bars represent standard deviation.

Figure 5 – Mean readjustment delay (Rd) of all players with teammates according to coupling strength level (from the 1st to the 9th most coupled teammate). Each bar depicts one practice session (i.e., one week out of a total of twelve analysed sessions). Trend lines depict the best linear fit (least squares) for delays across matches according to teammate's coupling strength level. Linear regression slopes and coefficients of determination (R^2) are displayed on top of each category. In Team A, while R^2 values are very low, the slopes are consistently negative supporting the progressive decrease on Rd.

Figure 6 – Performance indicators (shots, ball recoveries and percentage of ball possession), player couplings (Pc) and team couplings (Tc) for teams A and B (Figures 6A and 6B, respectively) throughout the football program. Figures 6C and 6D depict the readjustment delay, in seconds, for the 1st (bottom of each bar) and 9th (top of each bar) most coupled teammates of teams A and B, respectively. The length of each bar represents the average time taken for all players to be synchronised once started team synchronisation.

APPENDIX

Frequencies of shots, ball recoveries (Ball Rec.), percentage of ball possession (Poss. %) and goals (AvB for 1st and 2nd halves); mean ± standard deviations of players' couplings (Pc), team couplings (Tc) plus readjustment delay (Rd) in seconds (for the 1st and 9th most coupled teammates) for teams A and B, in each half. The final column (PR) refers to the players' regularity in each team (i.e., the number of outfield players from the initial formations that were repeated across matches – goalkeepers excluded).