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Research article

Effects of Spatiotemporal Constraints and Age on the Interactions of Soccer Players when Competing for Ball Possession

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Abstract
Although there are several descriptions of interpersonal coordination in soccer teams, little is known about how such coordination is influenced by space and time constraints. In this study, we analyzed variations in interpersonal coordination under different marking intensities and across different age groups. Marking intensity was manipulated by changing the players' game space and time of ball possession in a conditioned soccer game known as *rondo*. Five participants in each age category (U13, U15, U17, and U20) performed *rondo* tasks in four experimental conditions, in a total of 134 trials. The dependent variables considered were pass performance and eco-physical variables capturing the player-environment coupling, such as coupling of the *marking* between players. Our results demonstrate that in soccer: (1) markers and passers are tightly coupled; (2) the marker-passer coupling emerges from a flexible and adaptive exchange of passes; (3) the marker-passer coupling is stronger in markings of higher intensity and older age groups. Thus, the interactions between soccer players in marking can be analyzed as an emerging and self-organized process in the context of group performance.

Key words: Ecological dynamics, marking coupling, interpersonal coordination, soccer.

Introduction

The dynamics of combined passes is thought to be one of the most striking features of modern soccer (Tenga et al., 2010). Barcelona FC, for example, typically has a game style (Chassy, 2013) characterized by fast, accurate, and locally built passes capable of breaking the stability of the opposing team (Paixão et al., 2015). This style of play was considered an evolutionary phenomenon in elite soccer (Barreira et al., 2015) and has attracted the attention of spectators, coaches, and sports scientists. For example, Paixão et al. (2015) showed that players using this style act more grouped, particularly in the half field sector, due to the defensive strategies and balance between the teams. This configuration caused higher density and congestion of players in the center of the field, thereby affecting the distances covered by the players, their passing style, and the overall ball speed (Kuhn, 2005). Thus, to perform a successful pass and take advantage of the action opportunities offered by the dynamic structure of the game, a player needs to perceive the location of a teammate and then pass the ball with a specific speed and direction. Indeed, in competitive team games, opportunities to make a pass arise and disappear according to the spatiotemporal relationships established between competing performers (Travassos et al., 2012a).

Recently, ecological dynamics has been proposed as a reliable theoretical framework to examine sport performance based on performer-environment relationships, i.e., at the ecological scale of analysis (Araújo et al., 2006). These studies revealed that players couple their actions in space and time to information emerging from key environmental and task constraints during performance (Travassos et al., 2012c). Thus, successfully using the opportunities for action (i.e., affordances) that emerge as individuals interact with their environment ultimately sustains adaptive performance behaviours and task achievement.

The ecological theoretical approach raises the hypothesis that experiencing unfavourable situations in the teaching-learning environment encourages players to explore the information from key environmental and task constraints and thereby create potential innovative game-play solutions (Davids et al., 2013; Passos and Davids, 2015; Silva et al., 2016). A few studies examined how the manipulation of specific constraints in small-sided and conditioned games (SSCG's), such as the number of players (Silva et al., 2015; Travassos et al., 2012c) and the spatial dimension of the game (Silva et al., 2014; Vilar et al., 2014), can influence interpersonal interactions. Indeed, such manipulations affected the spatial relationship between the players because they imposed continuous and diversified co-adaptations between attackers and defenders. For example, decreasing relative space constrains the interactions between players, as they have less time and space to act. These spatiotemporal constraints produce new information for ball-passing opportunities, which in turn promotes certain patterns of behavior by teammates and opponents. Previous research addressing the effects of field dimensions on tactical behavior reported different co-adaptations among players, depending on the available space between them. Silva et al (2014) observed larger trajectories of the players' movements in smaller game spaces. In addition, Vilar et al. (2014) showed that in smaller spaces, the players reduce their ball possession time by encouraging the exchange of passes and by increasing the rhythm of the game. These results suggest that key manipulations force players to engage in different functional-tactical behaviors, such as dribbling, passing, kicking, and marking, to create potential game-play solutions.

A specific type of SSCG's used by soccer coaches to reinforce local problem-solving (e.g., controlling and exchanging passes under the pressure of marking) is known

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as "rondo". Rondo is the term popularly used in Europe, but it can also be known as "bobinho" in South America, or by the recreational term "piggy in the middle" in the USA. The rondo game is a traditional activity in soccer used in various countries and contexts of sport action, such as recreational, educational and professional (DiBernardo, 2014). In this game, the players engage in combined passes while being pressed by a marker, and they are typically in numerical inferiority and have short time windows and space of action. The marker(s) must try to intercept the exchange of passes or force the opponents to error under a delimited area. On the other hand, the passers must keep the marker(s) as far as possible and exchange passes between them to maintain possession of the ball. Almost everything that happens in a soccer match other than kicking to the goal can be simulated in the rondo in its many possible configurations. Moreover, many coaches believe that the dynamic interpersonal interactions involved in the exchange of marking passes promote the development of functional and adaptive skills for space exploration/occupation in a soccer match environment (DiBernardo, 2014).

Although rondo is widely used and popularized in soccer, few studies describe the characteristics of this game or the patterns of marking behaviour that emerge from this competitive context. This type of information is, however, important for soccer coaches aiming to organize their activities according to the intended behavior.

Travassos et al. (2012d) analyzed ball velocity and passing accuracy data in an exchange-of-passes training situation involving four passers, and found that the characteristics of these passes were similar to those from a formal game of futsal. These results suggest that this particular task (training situation) has the ideal configuration to reproduce the characteristics of passes in the game situation (see representative design, Pinder et al., 2011; Araújo and Davids, 2015).

We propose that the inclusion of a marker in the center of the exchange of passes may influence the players' pass options by limiting the formation of pass lines, similar to situations of triangulation of pass exchanges, as in the formal game context. Thus, we hypothesize that rondo expresses characteristics of team synergies (Araújo and Davids, 2016) such as: (1) dimensional compression, which can be analyzed by team behavior-composed variables such as geographical center; and (2) an inherent tendency for self-organization (i.e. interpersonal dynamics push the system into a state of order) as a function of the task constraints; (3) reciprocal compensation between players; and (4) degeneracy (i.e., flexibility in the ways to achieve the same goals).

In this study, we test this hypothesis by analyzing the effects of manipulating playing space and ball possession time on the coupling between marker and passers with an experimental protocol based on rondo. By using the configuration defined by Travassos et al. (2012d), we also assessed whether these interpersonal interactions between players differed between age groups.

Our specific objectives were: a) to analyze the characteristics of the passes, specifically, interpersonal distance between the passer and the marker, interpersonal distance between the passer and the receiver, interpersonal distance between the marker and the receiver, angle and speed of each of these passes; b) to analyze the players' correlations (coupling strength and the time lag) between the passers (represented by the passers group centroid) and the marker throughout a rally; and c) to determine the differences in the characteristics of the passes, and in the players' correlations, between age groups (U13, U15, U17 and U20).

Methods

Participants

Twenty (n = 20) Brazilian male soccer players participated in this study. The participants were selected in a distributed manner across four training categories: U13 (n = 5), U15 (n = 5), U17 (n = 5) and U20 (n = 5). The data for each group is shown in Table 1.

The inclusion criteria for this study were that the participants: (1) had trained for at least one year in the club analyzed; (2) played in a outfield position (defender, midfield or forward positions); and (3) had taken part in official competitions (regional, state and/or national).

All participants and their parents were informed verbally and in writing of the aims and requirements of the experiment. For the participants under 18 years old, the parents signed an informed consent. The research project was fully approved by the Ethics Research Committee of the Santa Cruz State University (Brazil) with protocol number CAAE: 28947714.7.0000.5526 according to the Declaration of Helsinki.

Task design

The task was carried out in a grass field of the training club. The experimental task was based on the rondo game with the configuration of four (n = 4) passer players and one (n = 1) marker player (Figure 1A). Four experimental conditions were presented: (1) expanded space and free pass (EF), (2) expanded space and direct pass (ED), (3) restricted space and free pass (RF), and (4) restricted space and direct pass (RD).

In the expanded and restricted space conditions, the participants were allowed to move inside a circular spatial dimension of 9 or 6 meters in diameter, respectively. In both conditions, the marker started the task in the center of the circle, and the passers could position themselves freely inside the circle (without moving beyond the border).

Table 1. **Characteristics of the participants in each age category. Data are means (±SD).**

Category	Age (months)	Weight (kg)	Height (m)	Time competitions (months of experience)
U13	163.0 (5.7)	47.5 (7.8)	1.50 (.15)	24.0 (33.9)
U15	180.0 (6.9)	51.3 (3.9)	1.7 (.12)	81.0 (24.7)
U17	205.0 (11.5)	66.6 (7.1)	1,8 (.10)	79.2 (33.5)
U20	224.0 (7.6)	71.2 (4.8)	1.80 (.13)	96.0 (39.8)

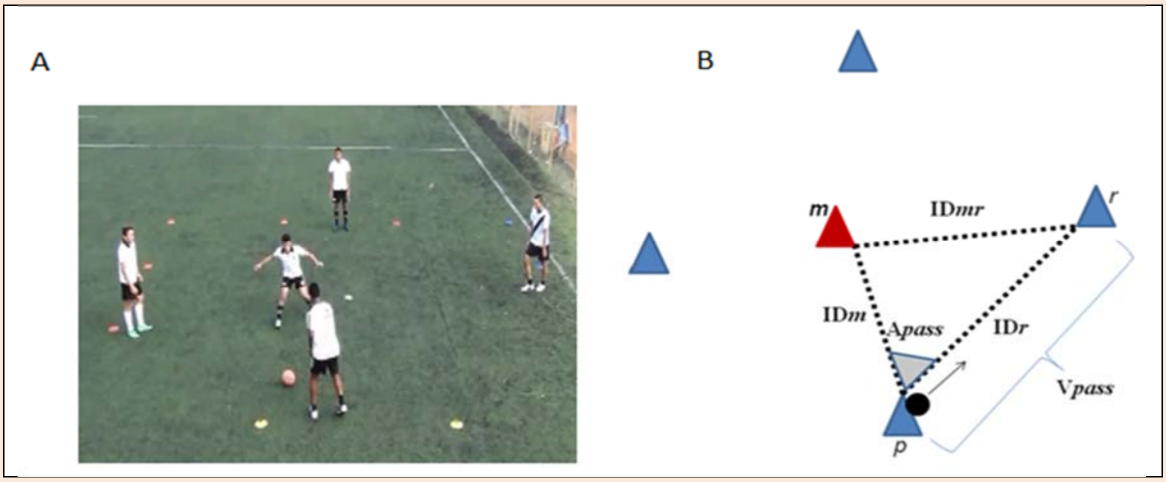

Figure 1. Configuration of the experimental task with four passers and one marker (in the middle) (A). The analyzed variables (B): ID*m*: interpersonal distance to the marker; DI*r*: interpersonal distance to the receiver; ID*mr*: interpersonal marker-receptor distance; A*pass*: pass angle; and V*pass*: average pass velocity.

In the free-pass condition, the passers had no any restrictions on ball possession and could therefore easily keep the ball under control, statically or dynamically, whenever and wherever they wanted. In contrast, in the direct-pass condition, the passers could not touch the ball more than once, and therefore had to receive and pass the ball with one touch only.

The task manipulations aimed to change the intensity of the marking and the movement of the ball during game performance. The dimensions of the circle were selected to maintain the passers in a spatial region of instability (i.e., reachability; approximately 3 to 4 meters between players), and therefore to allow them a short time for decision-making. The direct pass condition aimed to promote ball exchanges during game performance, thereby influencing pass flow and marking behavior.

Procedures

Each of the four experimental conditions (EF, ED, RF and RD) lasted for five minutes without interruption, in a total of 20 minutes of game activity. For each condition, 3 continuous minutes were considered for data analysis, and the first and last minutes were discarded. This procedure was adopted to avoid possible learning and fatigue effects. The participants were allowed 5 minutes of rest between each condition for physical recovery and for receiving instructions for the next experimental condition. Every age group performed the conditions in the same order: EF, ED, RF, and RD. All participants had knowledge of the rondo game and practiced it daily in their training sessions.

The passers were instructed to exchange passes between them according to the rules of each condition while avoiding the ball to be intercepted by the marker. In addition, the players were instructed to perform passes while keeping the ball as close to the ground as possible. The marker was asked to intercept the passes. The task was stopped and a trial (or rally) was computed when the passers lost possession of the ball either by (i) failing a pass, (ii) inadequate possession (e.g., two touches in the direct-pass condition); or (iii) direct confrontation or interception of the ball by the marker. In subsequent trials, the player responsible for the error assumed the position of the marker (which was previously fixed). When there was a disagreement in the game, a referee (the experimenter) would evaluate the play and give indications for re-initiating the game. The ball used for the match complied with the official measures of each age group. The task was performed on the soccer field of the training center and was preceded by a 15-minute warm-up guided by a coach, including light races, ball passes, and upper and lower limb stretching.

The data of interest were obtained by means of videogrammetric procedures captured by a Sony HD Progressive digital camcorder (model HDR-XR260) configured for recording at 25 Hz. The camera was positioned on a specific support oat an elevated plane (10m) at a distance of 10m from the center of the performance area (location of the marker starting position). The focus of the video camera was directed to the center so that it would capture the five players and ball displacements as well as the entire playing area. The settings adopted for the filming followed the methods in Duarte et al. (2014).

After video-recording the task, we analyzed the video-clips in the laboratory to select the trials for analysis according to the following criteria: (1) the players and the ball should remain inside the spatial limits of the circles; (2) all passes should be carried out near the ground (ground passes); and (3) there should be at least four consecutive passes without interception of the marker or ball loss. These criteria were adopted because they are normally used in rondo and also to retain the match in the calibrated space, with the minimum variations in the vertical plane as possible.

The footage of each clip was analyzed to identify the beginning and end of each trial. The start of each trial was the moment when a passer received the marker pass (contact with the ball). The end of each trial corresponded to the moment of ball interception by the marker, or to the last moment the passer contacted the ball before losing it (e.g., failed pass). In total, we analyze 816 passes among 134 rallies. These events characterized the sample analyzed in this study (Table 2).

Table 2. Number of rallies and passes by task constraints in each age category.

Category	Condition	Nº Rallis	Nº Passes
U13	EF	7	43
	ED	9	43
	RF	10	46
	RD	10	59
U15	EF	8	50
	ED	8	55
	RF	9	48
	RD	9	54
U17	EF	9	56
	ED	9	55
	RF	10	52
	RD	7	49
U20	EF	7	50
	ED	8	50
	RF	8	55
	RD	6	51
Total		134	816

The videogrammetric procedure was performed by Digital Video for Windows software (Laboratory of Biomechanics and Computer Science Institute – Unicamp, 1998 – version 5.1; Barros et al., 1999). The motion trajectories of the ball and the players were digitized and virtual coordinates (i.e., in pixels) data were transformed into world pitch coordinates (i.e., in metres) by using the bi-dimensional direct linear transformation method (2D-DLT) (Duarte et al., 2014). The time series were filtered with the Butterworth low pass filter (cut-off frequency of 6 Hz (Winter, 2005) by using MATLAB software (Matlab 8.0, The Matworks Inc., 1998).

The digitalization was performed through semi-automatic tracking using automatic identification and tracking functions (and, when necessary, the computer mouse). The projection of the trunk alignment to the ground was used as reference for the registration of the players, and the center of the ball was used as reference to the registration of the ball, according to previous studies (Mcgarry et al., 2002; Mcgarry, 2009).

To transform the units of measure from pixels to centimeters (two-dimensional reconstruction), we used spatial coordinates obtained with 13 markers placed evenly in the field space. The first marker was considered as the origin (x = 0 and y = 0) of this system and all the other points were computed from this origin. The "x" and "y" axis corresponded to the mid-lateral and longitudinal directions of the field, respectively.

To determine the accuracy and reliability of the image digitization process, an image was randomly selected to be re-digitized by the same investigator (intra-investigator assessment) and by a different investigator (inter-investigator assessment). The technical error of measurement (TEM) and the coefficient of reliability (R) were then calculated (Goto and Mascie-Taylor, 2007). TEM was calculated by $\sqrt{(\sum D2/2N)}$, in which D is the difference between the two measurements and N is the sample size. R can vary from zero (unreliable) to one (completely reliable) and was calculated by 1-(TEM 2/DP2), in which DP is the standard deviation for all measurements. The intra-investigator TEM was 0.091m (0.167%) for the players and 0.021m (0.097%) for the ball. The intra-investigator R was 0.981 for the players and 0.984 for the ball. In terms of the inter-investigator assessment, TEM values were 0.097m (0.173%) for the players and 0.023m (0.098%) for the ball. Finally, R was 0.978 for the players and 0.980 for the ball.

Data analysis

Variables

The three independent variables were: age category (U13, U15, U17 and U20), spatial task constraints (large or small), and temporal task constraints (with or without maintenance of ball possession). The dependent eco-physical variables captured the interpersonal configuration in each pass event (static measures), and the temporal evolution of the interpersonal interactions across each rally (dynamic measures), i.e., time series of the distances from each player to the ball and to other players.

These eco-physical variables can be visualized in Figure 1B and were described as:

(a) Interpersonal distance between the passers and the marker (IDm): measured by Euclidean distance between the position of the passer and the position of the marker;

(b) Interpersonal distance between the passer and receiver (IDr): measured by the Euclidean distance between the position of the passer and the position of the receiver;

(c) Interpersonal distance between the marker and the receiver (IDmr): measured by the Euclidean distance between the position of the marker and the position of the receiver;

(d) Pass Angle (Apass): measured by the cosine law considering the vectors IDm and IDr;

(e) Average Pass Velocity (Vpass): measured by the spatial variation ratio and the time interval between the pass and reception.

The time series data were obtained from:

(f) Distance between the ball and the marker (Dbm): measured by the Euclidean distance between the position of the ball and the position of the marker;

(g) Distance between the ball and the centroid (Dbcent): measured by the Euclidean distance between the position of the ball and the position of the centroid.

All variables were calculated in Matlab software. The interpersonal distances were obtained with the equation $D = \sqrt{(P2x - P1x)^2 + (P2y - P1y)^2}$, where "D" refers to the distance between players (P1 and P2). From the distance values, the pass angle was calculated with $cos\theta = \alpha^2 - (b^2 + c^2) / -2bc$, where "a", "b" and "c" refers to the distances between the points that form the angle of interest. The average pass velocity was obtained through the equation $V = D\Delta / \Delta t$, where "D" refers to the Euclidean distance and "t" is the time of ball displacement. Finally, the centroid was obtained with the equation $cent = (D_{p1} + D_{p2} + D_{p3} + D_{p4}) / 4$, where "D_p" refers to the Euclidean distance of the passer relative to the origin.

Interpersonal coordination calculation

We performed an in-depth analysis of the interpersonal coordination between marker and passers in all the experimental conditions by using techniques of running correlations and cross-correlation.

The running correlations allow a continuous analysis of the players' movements over time (time series data) and may identify coordination trends that are synchronic, asynchronous or non-synchronized (see application in Araújo et al., 2006; Corbetta and Thelen, 1996; Correia et al., 2014; Kelso et al., 1981; Meador et al., 2002). To calculate the running correlations between Dbm and Dbcent, a 0.4s window (i.e., 10 points) was shifted frame by frame every 0.04s and, at each offset, a correlation value was calculated. We obtained a continuous correlation function that described the coordination tendencies between marker and centroid over time. To perceive the coordination tendencies, the set of correlation values measured in each trial was plotted in a frequency histogram by dividing the correlation values from -1 to +1 into 20 ordinal categories and, subsequently, by normalizing the frequencies (i.e., dividing them by the total number of correlation values in each trial). The distributions obtained indicate if the coordination tendencies are in in-phase, anti-phase, or out-of-phase. Finally, we calculated the distributions for each experimental condition.

The cross-correlation analyses were also applied the Dbm and Dbcent time series to assess the degree and time lag between the marker and the centroid. The time displacement comprised 10 lags for the positive and negative directions: t – k and t + k, klag = 0.08s (Amblard et al., 1994; Correia et al., 2014; Mullineaux et al., 2001).

The running and cross-correlation analyses were performed qualitatively in every experimental condition with time-series graphs that showed the coupling between the marker and the centroid.

Statistical procedures

For each static measures (pass event), we used two-way ANOVAs considering as factors the levels of age category (U13, U15, U17 and U20) and experimental manipulations (EF, ED, RF and RD). A post hoc Bonferroni test was used when the ANOVA showed a main effect or interaction between the factors. Shapiro-Wilk's W and Bartlett normality and homogeneity tests of variance were performed by using the Statistical Package for the Social Sciences software (version 20.0 - SPSS Inc.) with a level of significance set at $p < 0.05$. All significant differences were presented with standardized Cohen differences computed with pooled variance and 95% confidence limits. Thresholds for effect size statistics were 0.2 = trivial, 0.6 = small, 1.2 = moderate, 2.0 = large, and > 2.0, very large (Hopkins et al., 2009).

Results

Game dynamics

The distance to the ball allowed us to describe the spatio-temporal interactions between the players. Figure 2 shows the results for one of the trials as an example. It is important to note that the exchange of passes has periodic characteristics in rondo. In Figure 2A, lines represent the players, and waves (moments when the time series reaches values close to zero, as identified by the reduction and subsequent increase of the values) represent the time and duration of the contact between the player and the ball (large waves: longer maintenance of ball possession between reception and pass; narrow waves: reception and direct pass, in one touch).

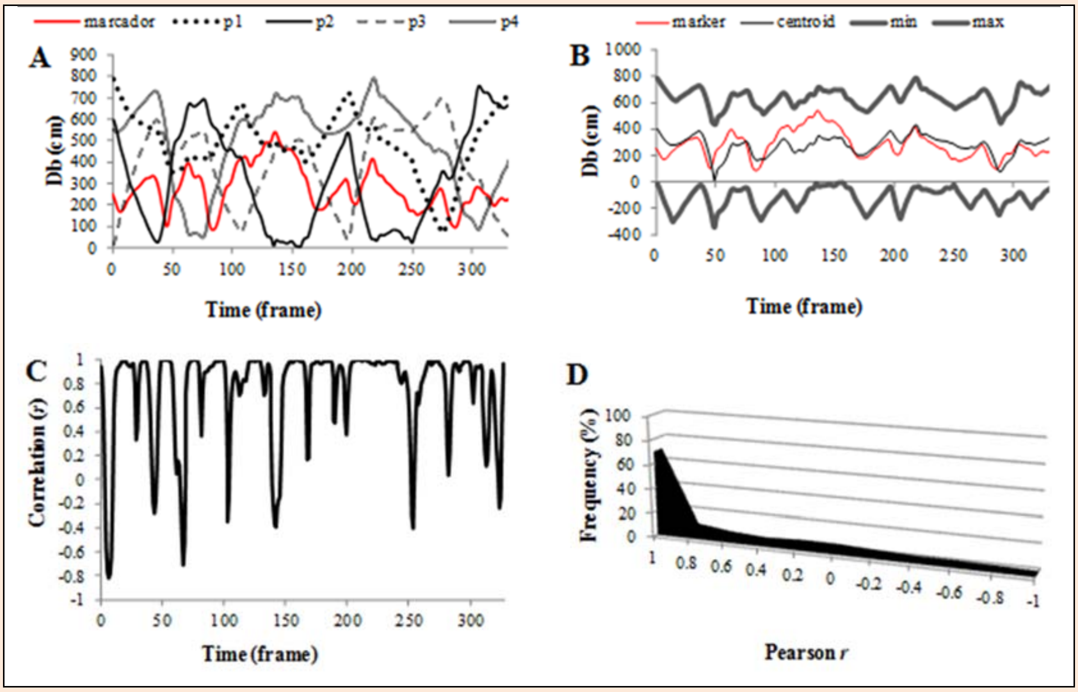

Figure 2. Description of the space-time interactions of the players in the game through ball distance. A: Time evolution of the distance to the ball for each player (p1, p2, p3, p4 and marker). B: Time evolution of the distance from the ball to the centroid and the marker. C: Time evolution of the coordination between marker and centroid. D: Landscape of interaction patterns between marker and centroid.

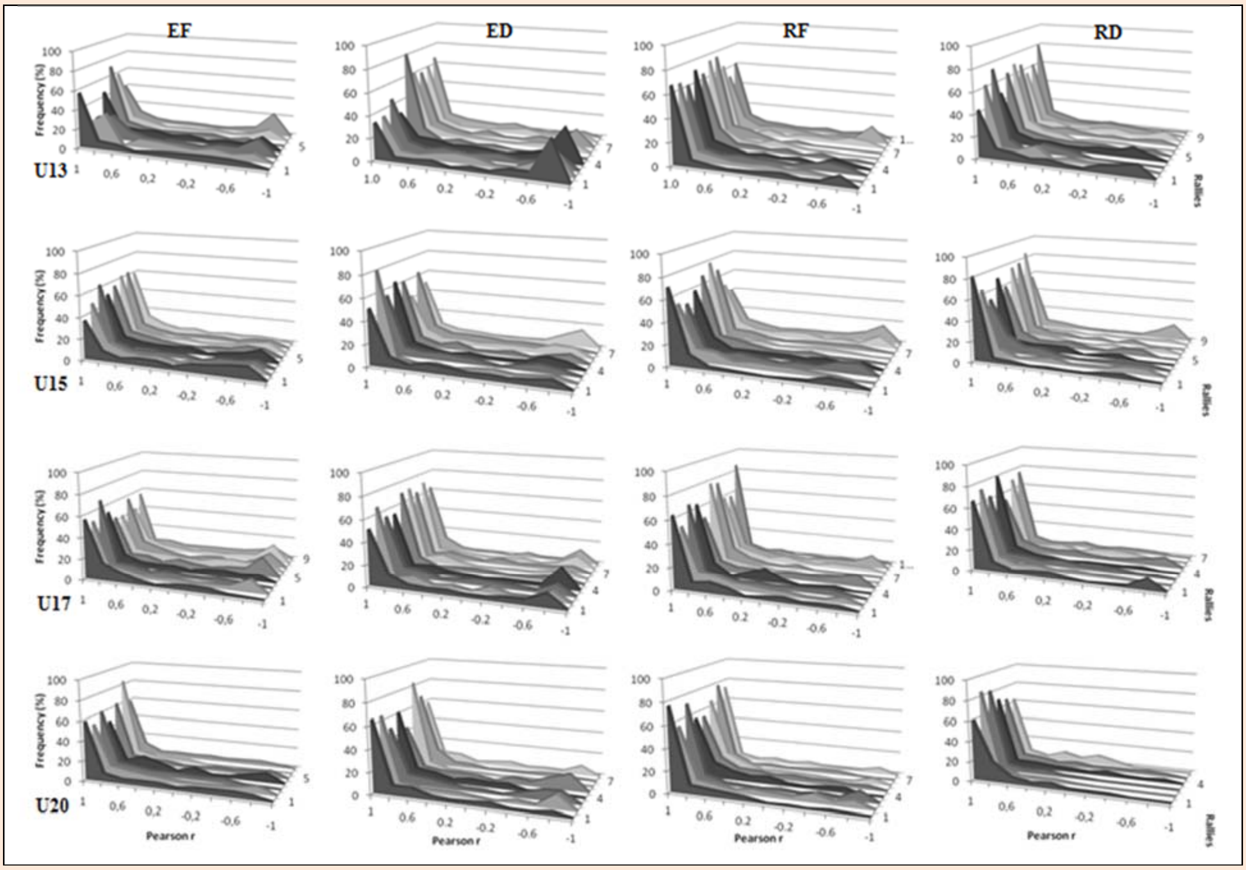

Figure 3. Landscape of interaction patterns between marker and centroid. The lines correspond to the different age categories and the columns correspond to the different task constraints.

Figure 2B shows the four passers represented by the centroid. The max and min time series represent the space limits of the rally (calculated by the max and min values, point to point, of all passers) and how marker and centroid interact internally to these limits.

An oscillatory movement between marker and centroid can easily be observed. We also registered the moments when the marker is closest (lower value) or furthest (higher value) to the ball relative to the centroid, as well as the moments of transition (crossing between sets).

Figure 2C shows the coordination between the marker and the centroid over time, thereby revealing the moments when symmetries are created, maintained, or dissolved throughout a rally. The examples presented show moments when the marker and centroid were symmetrical (coordination in phase, values between 0.8 and 1), antisymmetric (anti-phase coordination, values between -0.8 and -1), or asymmetric (out-of-phase coordination, values between -0.8 and 0.8).

Finally, Figure 2D shows the frequency analysis of the running correlations. There is a zone of higher frequency (corresponding to values between 0.8 and 1), which characterizes an attractor state and therefore indicates synchronized coupling. Zones corresponding to asynchronous (values between -0.8 and 0.8) and non-synchronized (values between -1 and -0.8) coordination modes are observed at lower frequency.

In-depth analysis of the interpersonal coordination

Interpersonal coupling tendencies

Figure 3 shows the landscape for the frequency analysis of the running correlations corresponding to the age categories and task constraints conditions.

The results reveal that synchronized coupling is an attractor state in all rallies, and zones corresponding to asynchronous and non-synchronized coordination modes occur less frequently. In the experimental conditions with extended playing space (EF and ED), the asynchronous coordination zone occurs more frequently, possibly indicating another attractive state. Under reduced playing space conditions (RF and RD), there was strong synchronized coupling, particularly in the direct pass condition (RD). The age category showed similar trends, with more advanced categories having greater synchrony and less antisynchrony.

Interpersonal coupling latency

Figure 4 shows the latency of interpersonal coordination calculated by the Dbm and Dbcent cross-correlations corresponding to age categories and task constraints. Solid lines represent the moving average of the correlation coefficient and dashed lines represent the moving standard deviations upwards and downwards.

The results show a tendency for a positive correlation between 0.5r and 0.75r. Positive coefficients suggest the participants moved with moderate synchrony throughout the time series. The peaks of the curves in the "y" and "x" axis represent the global magnitude of the correlation and the time lag of the coupling between the marker and the centroid, respectively.

The category U20 shows higher magnitude of correlation and smaller time lag (peak located in Lag 0). In contrast, categories U13, U15 and U17 have a peak with smaller magnitude and some temporal delay. These results suggest that all categories have strong coupling, however, the coupling relationships show some temporal delay.

The analysis of the task constraints revealed that the strongest couplings (larger peaks) corresponded to the conditions with reduced playing space (RF and RD). Moreover, the more restrictive condition (RD) presented smaller (or no) time lag (peak closer to Lag 0).

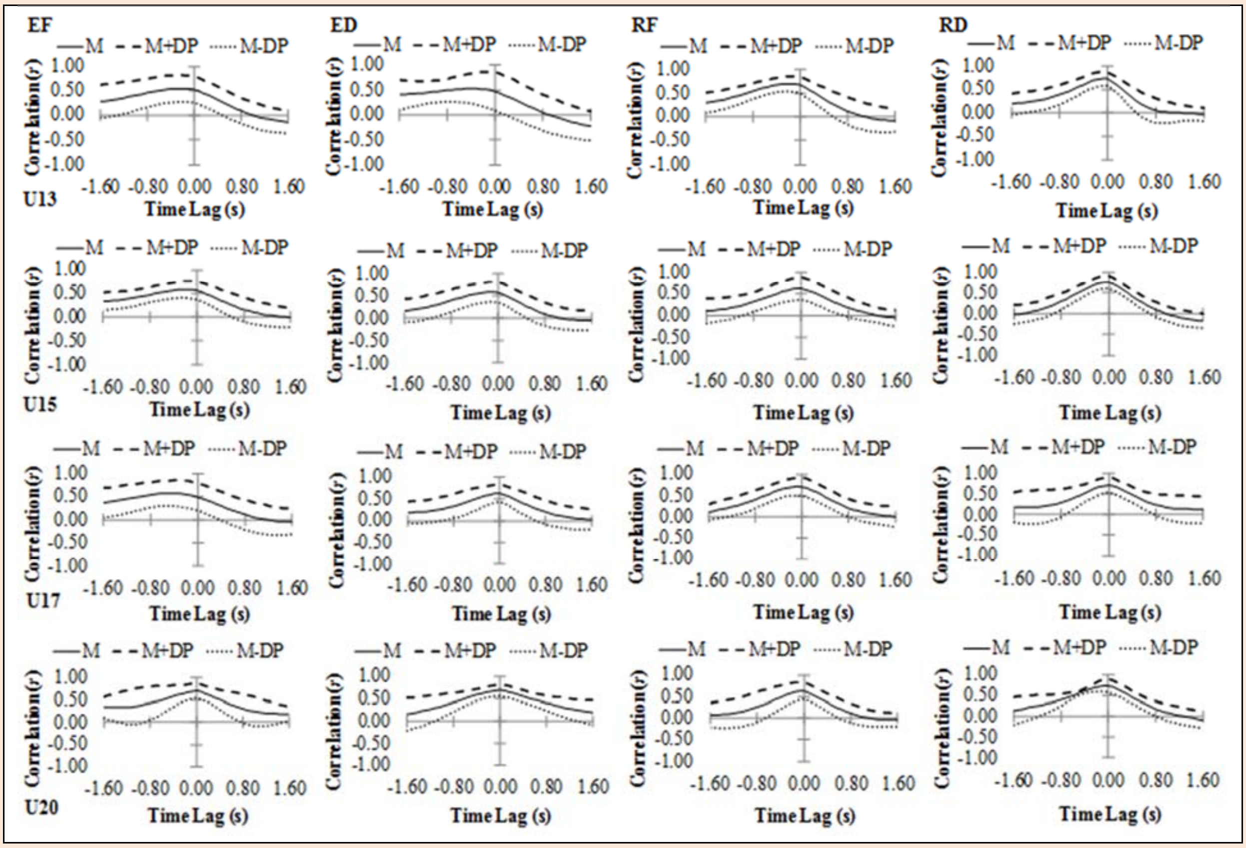

Figure 4. Mean and standard deviation (M ± SD) point-to-point for the cross-correlation coefficient between D*bm* and D*bcent* in the different time lags. The lines correspond to the different age categories and the columns correspond to the different task constraints.

Characteristics of the passes in the different experimental conditions

Figure 5 shows the interpersonal distances, pass angle, and average pass velocity in the different experimental conditions and across the different age categories.

For the IDm, the Anova two way indicated a main effect for task constraints ($F_{3,800} = 113.351$; $p < 0.0001$), revealing there are significant differences between the extended and reduced playing space conditions (EF x RF: $p < 0.0001$, ES: 1.15 ± 0.21, moderate; EF x RD: $p < 0.0001$, ES: 0.99 ± 0.20, moderate; ED x RF: $p < 0.0001$, ES: 1.56 ± 0.22, large; and ED x RD: $p < 0.0001$, ES: 1.40 ± 0.21, large), and between the free pass and direct pass conditions in an expanded playing space (EF x ED: $p = 0.003$, ES: 0.28 ± 0.19, small). No significant differences between age categories were found ($F_{3,800} = 2.415$; $p = 0.065$). For IDr, there was a main effect for task constraints ($F_{3,800} = 390.564$; $p < 0.0001$), indicating there are significant differences between the expanded and reduced playing space conditions (EF x RF: $p < 0.0001$, ES: 2.45 ± 0.26, very large; EF x RD: $p < 0.0001$, ES: 2.62 ± 0.26, very large; ED x RF: $p < 0.0001$, ES: 2.18 ± 0.25, very large; ED x RD: $p < 0.0001$, ES: 2.35 ± 0.25, very large). No significant differences between age categories were identified ($F_{3,800} = 0.861$; $p = 0.461$). For IDmr, we found a main effect for task constraints ($F_{3,800} = 60.999$; $p < 0.0001$), indicating there are significant differences between the extended and reduced playing space conditions (EF x RF: $p < 0.0001$, ES: 0.95 ± 0.20, moderate; EF x RD: $p < 0.0001$, ES: 0.92 ± 0.20, moderate; ED x RF: $p < 0.0001$, ES: 0.98 ± 0.20, moderate; ED x RD: $p < 0.0001$, ES: 0.95 ± 0.20, moderate). No significant differences were found between the age categories ($F_{3,800} = 1.262$; $p = 0.286$). For the Apass, we found no significant differences. Finally, for the Vpass, the Anova two way identified a main effect for task constraints ($F_{3,800} = 59,212$, $p < 0.001$), age category ($F_{3,800} = 11.761$; $p < 0.001$), and interaction between the factors ($F_{9,800} = 2,239$, $p = 0.018$). The Bonferroni Post Hoc test identified significant differences between: (1) U13 and U20 in EF condition (ES: 0.66 ± 0.42, moderate); (2) U13 and all the other categories in the ED condition (U13 and U15, ES: 0.68 ± 0.42, moderate; U13 and U17, ES: 0.84 ± 0.42, small; U13 and U20, ES: 0.73 ± 0.43, small) (3) U13 with U17 and U20 in the RF condition (U13 and U17, ES: 1.10 ± 0.43, moderate; U13 and U20, ES: 0.53 ± 0.40, small. There were no significant differences in the RD condition. We also found significant differences between: (4) EF and all the other task constraints conditions for the U13 category (EF and ED, ES: 0.85 ± 0.45, moderate; EF and RF, ES: 1.28 ± 0.47, large; EF and RD, ES: 1.06 ± 0.43, moderate); (5) EF and ED with RF and RD for the U15 category (ES: 0.94 ± 0.29, moderate); (6) RD and the other task constraints' conditions for the U17 category (RD and EF, ES: 1.08 ± 0.42, moderate; RD and ED, ES: 0.99 ± 0.41, moderate, RD and RF, ES: 0.84 ± 0.41, moderate); and (7) EF with the other task constraints' conditions (EF and ED, ES: 0.61 ± 0.41, moderate, EF and RF, ES: 0.99 ± 0.41, moderate, EF and RD, ES: 1.55 ± 0.46, large), ED with RD (ES: 0.86 ± 0.41, moderate). We found no significant differences between RF and RD in the U20 category.

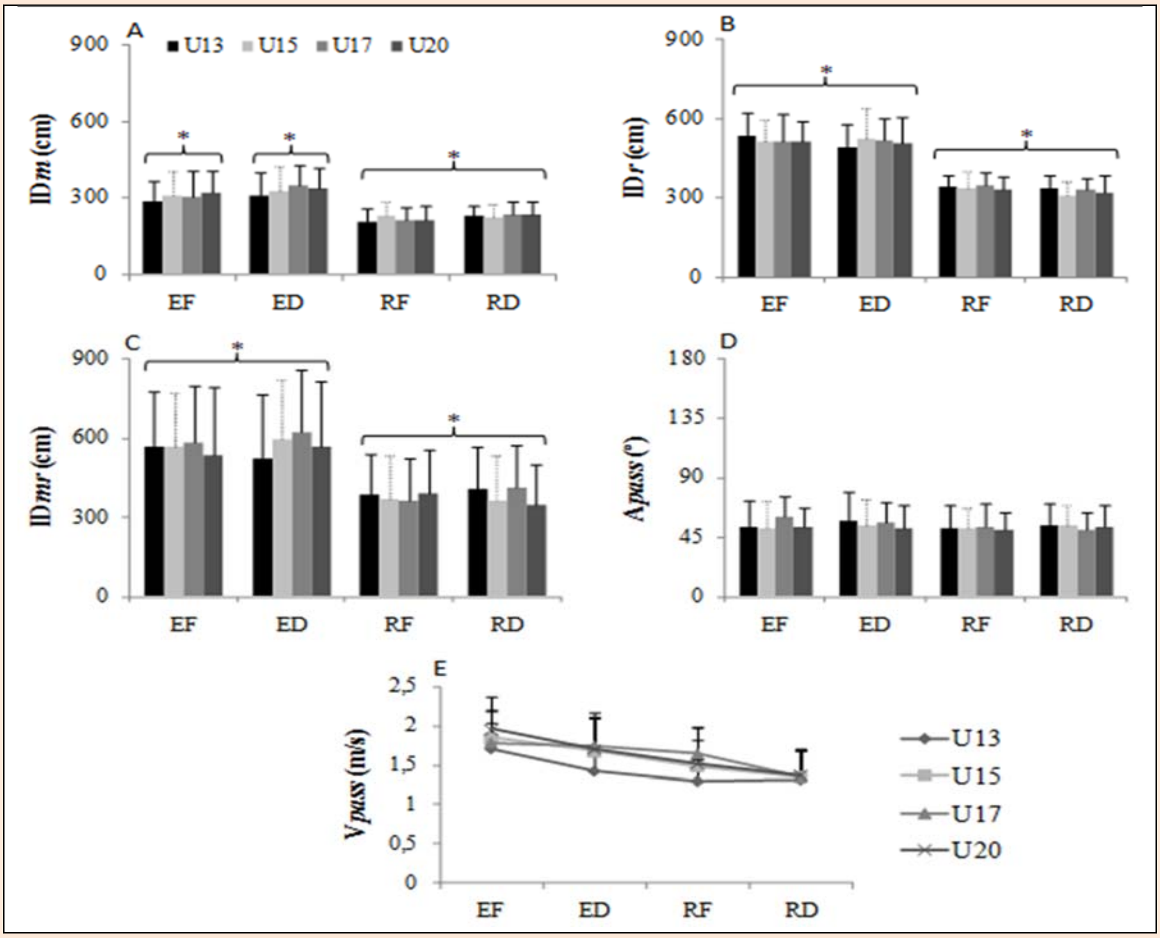

Figure 5. **Mean and standard deviations of each dependent variable in the different age categories and task constraints. EF: expanded space and free pass; ED: expanded space and direct pass; RF: reduced space and free pass; and RD: reduced space and direct pass. The parentheses indicate the groups of variables that did not present statistical differences. The asterisk indicates significant differences between groups of variables.**

Discussion

In this study, we aimed to understand interpersonal coordination as a co-adaptive and self-organized behavior in a performance context by analyzing the rondo game with an ecological dynamics perspective (e.g., Araújo et al., 2006). This approach allowed us to describe the exchange of passes between soccer players under continuous marking as an emerging, adaptive, and self-organized process. We hypothesized that the marker and the passers' centroid are coupled spatiotemporally and hence that this relationship may be shaped by spatial and temporal manipulations. Moreover, we aimed to test the hypothesis that the spatio temporal dynamics of the pass exchanges vary between different ages groups, specifically, with a tendency for increasing pass velocity and strength of marking coupling with age. We finalize this section by discussing some important limitations of this study and its theoretical and practical implications.

Marker-passers coupling

Rondo is a task in soccer practice in which players (passers) surrounding a marker exchange coordinated passes between them. Contact between passers and the ball continuously influences its trajectory and velocity, with the aim of keeping the marker in the center of the playing space. To create favorable conditions for the passes, the passers exploit the spatiotemporal relationships with the marker by moving throughout the game space. On the other hand, the marker tries to limit this space to destabilize the passes and create affordances for ball interception.

We measured coupling by following the displacement of the ball within the playing space. The distance between the players and the ball allowed us to describe the tendencies of interpersonal coordination, and the force and lag of the coupling between passers and marker, and therefore to test our first hypothesis. The results showed strong coupling and short time lag across all analyzed experimental conditions. Moreover, the marking coupling has a tendency to be stronger in the presence of task constraints and in older ager categories, which confirms our hypothesis.

These coordination tendencies revealed the complex nature of the systems and the effects that each player produces on the other players' behavior, and on the rhythm and flow of the game. Indeed, the running correlations could accurately describe the tendency of interpersonal coordination, specifically, we found that the synchronic coordination mode was predominant over the non-synchronized and asynchronous modes. The synchronic pattern was therefore a more attractive state (i.e., preferential state of the system), thereby revealing a preferentially symmetric marking in the analyzed performance context. Moreover, we could also show that the marking had short time lag with few variations between the experimental conditions (discussed below).

These results are in agreement with previous studies in basketball (Bourbousson et al., 2010a; 2010b), soccer (Duarte et al., 2012) and futsal (Travassos et al., 2011) revealing interpersonal and inter-team coordination tendencies. However, in the contexts of action analyzed so far, few studies have described the coupling of marking considering as reference the ball displacement on the playing field. In Travassos et al. (2011), movement trajectories of ball and players analyzed by their relative phase showed a trend for a symmetrical coordination between defenders and attackers. However, these authors examined the associations of the dyads based on the longitudinal and midlateral distances of the limits of the playing space, whereas in our study coupling was measured as a function of the displacement of the ball in the playing space. This difference in the methods may explain why we observed strong marking coupling in our experiments.

The time lag of the marking may be an indication of "who leads who" in the dynamics of the game (i.e. if marker or passers) (Correia et al., 2014; Riley et al., 2011; Silva et al. 2016). Our cross-correlation results showed short time lag, indicating that the marker responds promptly to the movement of the passers, and vice versa. It is interesting to note that the term "rondo" for this game suggests that the markers "watches" or "runs behind the ball". However, our results suggest that rather than "following" the ball, the marker adapts to the passers' actions and attempts to intercept the ball and therefore to impede the exchange of passes between them (discussed below).

An in depth view on the dynamics of interpersonal coordination in the different task constraints according to age

Our hypothesis that practice and experience in soccer may constrain the dynamics of interpersonal coordination in the rondo game predicts an increased tendency to strengthen marking coupling in older age groups. Indeed, analyzes of force and time lag between Dbm and Dbcent suggest that more experienced players use the available playing space more efficiently, resulting in a more stable collective behavior during the marking. These results are consistent with a previous study showing that younger, less experienced players occupied a smaller area with little lateral dispersion in the field (Folgado et al 2014), while older, more experienced players occupied a larger area in the field and moved in lateral and longitudinal directions. The authors proposed that younger players (with less maturity and experience) aimed to get closer to the goal quickly and played more individually (typically by dribbling) or used a less elaborate style of play. Moreover, Olthof et al (2015) showed that players in the U19 category have greater dispersion in the field when compared to U17 players. Consistent with this, our results in the rondo game suggest that younger players (particularly up to U13) perform a less elaborate style of play, by channeling their intentions and perceptions to the ball. In contrast, more experienced players employ more efficient tactics, with faster and more precise passes, and they also have higher greater efficiency in adapting to the marked player (i.e. receivers move to facilitate passing).

In a meta-analysis, Travassos et al (2013) reports that novice and expert players can be distinguished by their eye movements, decision times, and response accuracy. Thus, it is possible that increased marking coupling strength and synchronization may also result from the players' ability to share affordances at a global level, which is likely to increase with the level of experience (see discussion below). Indeed, experienced players produce more stable functional attractors to satisfy the constraints from competitive environment (Araújo and Davids, 2016).

The analyses of marking intensity revealed that playing space and time of ball possession constrain the interpersonal coupling. Smaller playing spaces restricted ball possession, increased the marker and centroid coupling force, and decreased the time lag of the synchronization. These results are in agreement with previous studies of dyads, subgroups and small games, which demonstrated that the proximity of the marking increases the strength of the attacker-defender coupling (Silva et al., 2014). Thus, in more restricted spaces the marker gains advantage due to the shorter distances within the pass lines (as discussed above) and to the co-adaptation of the marking. Stronger coordination and shorter time lag allow for a reduction in the degree of freedom, thereby restricting the range of action possibilities of the passers. Indeed, lowering the number of degrees of freedom makes the system more controllable (Bernstein, 1967). This control strategy can be identified in the increase of in-phase coordination, which directly reflects the performance of the marker.

The strengthening of the coupling in the competitive context within limited playing space and ball possession conditions can be explained by the sharing affordances (Silva et al., 2016). As aforementioned, the perception of the possibilities of movement and intentions of the other players (passers and/or marker) in a game situation sustain an interdependent relation of behaviors (Gibson, 1979). Thus, coupling is formed under a platform of communication channels (mainly visual and non-verbal) between the passers, and between passers and the marker, to perceive affordances of collective behavior (Passos and Davids, 2015).

Passes' configuration in the different task constraints according to age

We hypothesized that reducing playing space and limiting ball possession (i.e. more restrictive conditions) increases marking intensity and, as a result, the spatiotemporal characteristics of the passes changed. Moreover, we expected that differences in pass characteristics should occur between age groups, due to differences in experience.

We found that different playing spaces produced specific pass patterns, mainly due to changes in interpersonal distances between passer-marker-receiver. However, the manipulation of ball possession (free or direct pass) produced no significant differences. These results are consistent with previous studies demonstrating that interpersonal distance is associated with factors such as velocity and relative angle, which in turn influence coordination states, tactical behavior, and the flow and circulation of the ball during the game (Corrêa et al., 2012; 2014b; Silva et al., 2014; Vilar et al., 2012; 2014a).

It is important to highlight that unlike the formal soccer game, rondo does not allow territorial invasion and therefore dribbling is rarely used by the players (Corrêa et al., 2012; 2014a; Pepping et al., 2011; Withagen et al., 2012). In the formal game, dribbling actions emerge under low values of interpersonal distances during the marking, as the risk of pass interception increases (Travassos et al., 2012a). However, even in the absence of dribbling, rondo has a direct impact on the players' movement within the limited space and on how the passes are executed. Indeed, larger spaces favored the increase in pass velocity because the players can move more freely in the extended game space (Dellal et al., 2012, Kelly and Drust, 2009). Thus, in the extended playing space, the players aim to open spaces for creating pass lines (opportunities) and maintain possession of the ball (Lervolino, 2011), therefore resulting in changes in the velocity of the passes.

Previous research shows that more experienced players (age, time, and type of competition) seem to be able to optimize the playing space, with more dynamic and global movements (e.g., Silva et al., 2014). Other studies focusing on the players' technical performance (Malina et al., 2004; 2015) show that technical skills are strongly associated with the characteristics of growth and development, especially during puberty (for a review of these studies see Malina et al., 2015). Such studies suggest that the most striking differences in technical skills take place between the ages of 13 to 16 years old (Malina et al, 2015). Consistent with this, we found the most significant differences in Under-13 age category. Players in this age category appeared to have more difficulties in combined pass, particularly in reducing the velocity of the passes, which favors a possible interception at reduced interpersonal distances (Travassos et al., 2012b). Nevertheless, on average the rally time (7.5s + 4.4s) was similar to that in other categories. These results suggest that rondo can be successfully used in soccer practice with players as young as 13 years old. We found no statistical differences between age categories in the characteristics of the passes, suggesting that this variable has ample flexibility and is resilient to the task constraints. Moreover, these results show that across different age groups the players have diverse and creative solutions for maintaining in-game passes. Assuming that pass angle and average pass velocity can describe the conditions in which the exchange of passes is maintained, one can speculate that decreasing average pass velocity was a result of compensatory effects in the characteristics of the passes to support the coupling of the marking.

Although it may seem simple, a pass requires an efficient perceptual link to the performance context, since it depends on the perception of affordances emerging from the movement of the attackers and markers (Araújo and Davids, 2016; Stöckl et al., 2016). For an effective exchange of passes, the players must be well positioned in the field by forming interactions favoring the pass lines (Katis and Kellis, 2009). Passes open communication channels within the team, by promoting player mobility in the playing space and there optimizing the circulation of the ball in the field (Russell et al., 2010). Thus, the categories analyzed in this study offer wide versatility in response to the manipulated constraints, particularly concerning the ability of the passers to self-organize in the available space for maintaining the possession of ball.

Finally, the results of this study are consistent with the strong consensus in the literature that the optimization of space-time management in a game (and sub-phases of the game) depends on the level of development and experience of the players (Duarte et al., 2012; Duarte et al., 2013; Folgado et al., 2014; Olthof et al., 2015; Sampaio and Maçãs, 2012). These findings may help teachers and coaches to distinguish the different levels of coordination tendencies in players of different ages, and hence guide practitioners toward a coherent collective behavior in the process of player training.

Practical implications

We identified important structural and interactional configurations in the exchange of marking passes across different age categories that may serve as guidelines in the teaching-learning-training environment:

1) By manipulating the playing space and the possession of the ball in the rondo, it was possible to intensify the marking and influence the marking coupling;

2) The marking coupling was formed by a flexible positional configuration in the game, characterizing a self-organized process in the competitive context;

3) The patterns of interpersonal interaction (characteristics of the passes and coupling coordination) reveal

how players place themselves in the game and their style of marking;

4) Age and experience influence the marking coupling and the adaptations that emerge from specific performance contexts.

In light of these findings, the ecological dynamic approach is proposed as a theoretical matrix capable of providing an objective structuring of the teaching-learning-training environment. For example, our research using this approach reveals that skill acquisition and refinement depend on the adjustment of perceptual systems with specific performance contexts (Passos and Davids, 2015). Thus, tasks in practice contexts should provide specific ecological constraints to the players' interactions that are representative of the affordances in the game context. Our results suggest that rondo game is an activity that promotes the exploration and discovery of affordances in restrictive competitive contexts. Individually, the player must have the ability to efficiently occupy the playing space in order to successfully pass the ball to his teammate. Concurrently, the player must be able to reestablish a new positional configuration in response to the disturbance generated by the marking. The more spaces the teammates create near the player in possession of the ball, the greater are the options for the pass (lines of pass), and the higher are the chances of approaching the opponent's goal and scoring. At the collective level, interpersonal coordination is essential to ensure ball movement on the field (attack) and to hamper the advancement of the opponent (defense). Thus, it seems sensible to suggest that the ability to exchange passes reflects how quickly a team can change its configuration and move on the field as a whole.

Our results also give important contributions to the understanding of the effects of age and experience in the functional management of a team within a restrictive context. We found that player's age and experience influence the collective behavior of the team, probably because coupling force in the marking increases with age and experience. The discussed scientific literature emphasizes many maturational and developmental differences in the performance of various tasks. However, few studies have shown tendencies in interpersonal coordination in the context of small games. The results presented are consistent with previous research showing that more experienced age groups exhibit a more coordinated occupation of the playing space and that marking intensity affects the marker-attacking coupling. Thus, marking intensity can and should be manipulated within the practice environment.

Limitations of the study and future directions

One of the main challenges in professional soccer practice is the greater investment in SSCGs. It is important to highlight the need to further investigate the representativeness of the games used in training. In rondo specifically, it is possible to re-recreate a series of organizational principles from the formal game (and sub-phases or moments of the game). However, a significant difference between these games lies in the objective of the task, because unlike the formal game, rondo does not require territorial breakthrough. Thus, one can question the representativeness of this activity in the context of formal games. To our knowledge, this is the first study to address the representiveness of the rondo game to date. Previously, only one study analyzed a pass-training activity (Travassos et al. 2012d). Future studies should further explore the representativeness of this activity, as it could become a fertile field for research and intervention.

The challenge will be to analyze action fidelity through observation of kinematic data to compare individual or team behaviours that emerge under the constraints of specific practice tasks and competitive performance. This type of approach would help sport scientists to evaluate whether the successful transfer of performance skills has occurred from learning and practice environments to competitive performance settings.

Conclusion

This study gives important insights into the development and adaptability of marking in the *rondo* game by demonstrating how spatiotemporal and age-related constraints can influence the formation of coupling between players. Spatiotemporal dynamics was used to assess interpersonal interactions between players during the exchange of marking passes. The distance to the ball was a relevant variable to describe and analyze how marker and passers were coupled. We showed that: (1) marking and passers are tightly coupled; (2) the marking coupling emerges from a flexible and adaptive exchange of passes; (3) the marking coupling is strengthened according to the marking intensity (verified by the task constraints); and (4) the marking coupling is strengthened according to the category of football formation.

Based on these observations, we conclud that the coupling between perception and action in the context of action can regulate the performance in the game, thereby leading to adaptive changes in patterns of interpersonal coordination. Finally, this study provides considerable evidence that interpersonal interaction of marking can be analyzed in the language of dynamic and self-organized processes. Thus, our findings support previous research showing that regularity and changes in collective behavior can be understood as an emerging property of constraints that force players to behave as a functional, unified structure in the performance context.

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Key points

- Marking and passers players are tightly coupled in *rondo* game.
- The marking coupling emerges from a flexible and adaptive exchange of passes.
- The marking coupling is strengthened according to the marking intensity and to the category of football formation.

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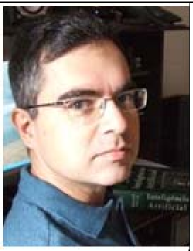

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