

Research article

How Training Tools Physically Linking Soccer Players Improve Interpersonal Coordination

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Abstract

Interpersonal coordination is an important skill for promoting collective behavior in team sports. This study tested the impact of two types of tools in facilitating triadic coordination. 16 males aged under 12 years were divided into four groups with similar skill levels and average ages. Each group performed a three-versus-one ball passing task under three conditions: a one-elastic-band tool linking the three players, a three-elastic-bands tool linking the three players, and without a tool linking the three players. The dependent variables were ball passing frequency, frequency and amplitude of inner angles of the triangle formed by the players, and duration of the synchronized patterns of the inner angles. The results show that neither tool increased ball-passing frequency or the duration of synchronized patterns. However, both tools increased the frequency of inner angles, and the three-elastic-bands tool decreased the amplitude of inner angles. From these results, we conclude that elastic-band tools affect spatial and temporal triadic formation by means of haptic and visual information. Specifically, compared with the one-elastic-band tool, the three-elastic-bands tool stabilizes the triadic spatial formation. We also explore the implications for how these tools can be used in practice.

Key words: Triadic coordination, haptic information, visual information, practical tool.

Introduction

Improving interpersonal coordination skills is a key issue for tactical performance in team sports (Menuchi et al., 2018; Passos et al., 2016). However, it has not received enough attention in the sports science literature (Sarmiento et al. 2017; 2018). This indicates that its practice is not guided by scientific knowledge but is mainly based on the preferences of coaches.

Team sport competitions have been conceptualized as complex dynamical systems composed of many interacting parts (e.g., Davids et al., 2005). A dynamical systems approach to sport performance describes how patterns of coordinated movement form, emerge, persist, and change. It builds on the insight that teams, as social systems, consist of many interacting parts, endowing them with a capacity for spontaneous pattern formation or self-organization. The spontaneous creation of coherent macroscopic patterns (e.g., group or team coordination) is important scientifically, and the resulting macroscopic patterns of the dynamics of one or a few collective variables or order parameters can be studied carefully (e.g., dyadic relative phase, Travassos et al., 2011; or cluster phase,

Duarte et al., 2013), without needing to record all of the microscopic states of the individual parts (e.g., the movement of each player; see Araújo and Davids, 2016).

Beyond the focus on operational measures and performance descriptors, interpersonal coordination benefits from theoretical guidance for the generation of hypotheses, interpretation of data, and design of interventions, including the design of learning equipment. The theoretical framework of ecological dynamics (Araújo and Davids, 2016) recognizes the “flexibility” of social systems (i.e., teams), and its principles can explain how the same performance outcomes can emerge from different behavioral patterns. Namely, the framework hypothesizes that team behavior, as a social synergy, emerges by means of self-organization, as a consequence of players’ perceptual attunement to shared affordances (Silva et al., 2016).

However, it is interesting to note that research has focused mainly on dyads (e.g., McGarry et al., 2002; Travassos et al., 2011) or, more sporadically, on clusters of entire teams (Duarte et al., 2012; López-Felip et al., 2018). The processes of interpersonal coordination for dyads and team clusters have commonalities, as well as distinctive characteristics. These distinctions led to a research program specifically focused on interpersonal coordination in small groups, namely groups of three players or triads. Specifically, triadic coordination patterns are a key component in the understanding of complex collective behavior in soccer games (Ramos et al., 2017; Yamamoto and Yokoyama, 2011). Research shows that these are among the most common coordination patterns during a soccer match. In rapidly changing game situations, players need to maintain different types of dyadic and triadic coordination (Ramos et al., 2017). From the perspective of a player, triadic coordination is the maintenance of two types of dyad coordination (Yokoyama and Yamamoto, 2011), and it is a key coordination pattern during a match.

Based on coupled oscillators as complex dynamical systems, Yokoyama and Yamamoto (2011) predict the synchronization patterns of rings of three coupled players during a three-versus-one ball possession task. The players’ synchronization was given by the three angles of the triangle made by the three players’ positions. The authors found that two types of synchronized patterns conformed to two of the three patterns predicted by the symmetric Hopf bifurcation theory. In a dynamical system, a Hopf bifurcation is a critical point where a system’s stability switches and a periodic solution arises (Stewart and Golubitsky, 1992; Strogatz, 1994). One of these patterns was a rotation pattern (R) in which the phase differences among

the three angles (adjacent oscillators) were almost equal to $2\pi/3$. This means that one of the angles of the triangle constructed by three players was larger than the other two angles, with a constant interval. The other pattern was a partial anti-phase pattern (PA) in which two of the angles were in anti-phase and the third angle frequency was null. The typical situation in this null frequency pattern is that the distance between two players (e.g. Player A and Player B) is kept constant, and the other player (Player C) moves on the arc line between two players (Players A and B).

Skill level in interpersonal coordination has also been found to play the role of a bifurcation parameter. Specifically, expert players tend to show R patterns more often than novice players did. In a follow-up study, Yokoyama et al. (2018) use mathematical simulations to examine how different expressions of interpersonal coordination, based on players' social synchronization skills, influence how they perform the same three-versus-one soccer task. The authors postulate three kinds of "forces" that underlie these social synchronization skills: spatial, avoiding, and cooperative forces. From their simulation data, they find that the so-called "cooperative social force" has a very important role in the interpersonal coordination of experienced players, though the specifics of this role are not addressed. Building on these results, Yokoyama et al. (2018) further develop a prototype three-elastic-bands tool that physically (haptically) facilitates players' perceptions of interpersonal coordination. Experimental results show that the three-elastic-bands tool influences novice players' relative positions, namely, the inner angles of the triangle formed by the three players. This same tendency is found among the expert players who master the "cooperative social force" skill.

However, it is not clear if and how these changes improve interpersonal coordination, leaving the effectiveness of this three-elastic-bands tool in question. The results of the simulations by Yokoyama et al. (2018) indicate that the use of this tool may increase the frequency of the R synchronization pattern and may decrease the frequency of the PA synchronization pattern. Specifically, if the strength of cooperative forces is larger, the frequency of PA patterns decreases, and the frequency of R patterns increases. Moreover, we can also predict that an increase in the symmetrical coupling of the players would cause a higher frequency of R patterns. With these two theoretical predictions, we develop a new one-elastic-band tool, connecting the three players simultaneously. Contrary to the three-elastic-bands tool, with the one-band-elastic tool, each player could haptically perceive the resultant force simultaneously generated by movements of the two other players.

Therefore, it is hypothesized for the study that players 1) will improve their triadic coordination skills with the help of a band tool, either with a one elastic band or with three elastic bands; and 2) the one-elastic-band tool will facilitate the R pattern more than the three-elastic-bands tool.

Methods

Participants

Sixteen male Japanese junior handball players participated in this study (mean age: 10.81 ± 1.16 yrs. old; max. age: 12

yrs. old; min. age: 9 yrs. old). Their experience in handball ranged from about four to six years, but they were novices in soccer. Their handball experience facilitated their involvement in team coordination tasks, even though they had not practiced them before in soccer. The participants were split into four groups composed of four players each, balanced by age and motor ability in team sports to enhance the internal validity of the experiment. The difference in average age between each group was within one year. The motor ability was assessed by their handball coach; the groups were adjusted so that these values would be as close as possible between each group.

We obtained informed consent from the participants and their parents. The experimental procedures conformed to the principles in the Declaration of Helsinki and were approved by the Ethics Committee of Kogakuin University.

Task design and tool conditions

The experimental task was a three-versus-one ball-possession task in soccer. In this task, three attacking players were instructed to exchange a ball with one another as many times as possible in 60 seconds without going out of the 7-square-meter area marked by tape on the floor. The defensive player was instructed to take the ball away from the attacking players as quickly as possible. The role of each participant (as attacker or defender) was decided before the experiment, and it remained the same in all trials. The defenders were selected based on their greater endurance ability than the other members in each group, as assessed by their coach, because defenders must move harder than attackers.

Three experimental conditions were presented: (1) the one-elastic-band condition; (2) the three-elastic-bands condition; and (3) the control condition. In the one-elastic-band and three-elastic-bands conditions, three attacking players performed the experimental task using the one-elastic-band and three-elastic-bands tools, respectively. In the control condition, players performed the experimental task without any tool.

As shown in Figure 1a, both tools were comprised of three belts and elastic bands physically connecting the three players (Japanese Unexamined Patent Application Publication No. 2017-18447). The difference between these two tools was the number of elastic bands. The one-elastic-band tool connected the three players by one long elastic band, and the three-elastic-bands tool connected each pair of adjacent players with a different elastic band, thus the tool has three separate elastic bands (Figure 1b).

In the groups using the tools, the participants used a belt that allowed for the placement of either the one-elastic-band tool or the three-elastic-bands tool (Figure 1c). The belt was made of nylon filament fabric; the bands were connected to the belts either through a 25 cm hole or with two hooks. In the one-elastic-band tool, the elastic band was put through the band hole. The hole through which the band runs is in the part of the belt at the player's back. This means that the tension from the elastic band works on the player's back. In the three-elastic-bands tool, the two elastic bands connected the left and right hooks of each player. Therefore, the tension from the three-elastic-bands tool works on the players' left and right sides along their

hips (Figure 1b). As a result, the direction of force haptically perceived by the players was different between the one-elastic-band tool and the three-elastic-bands tool.

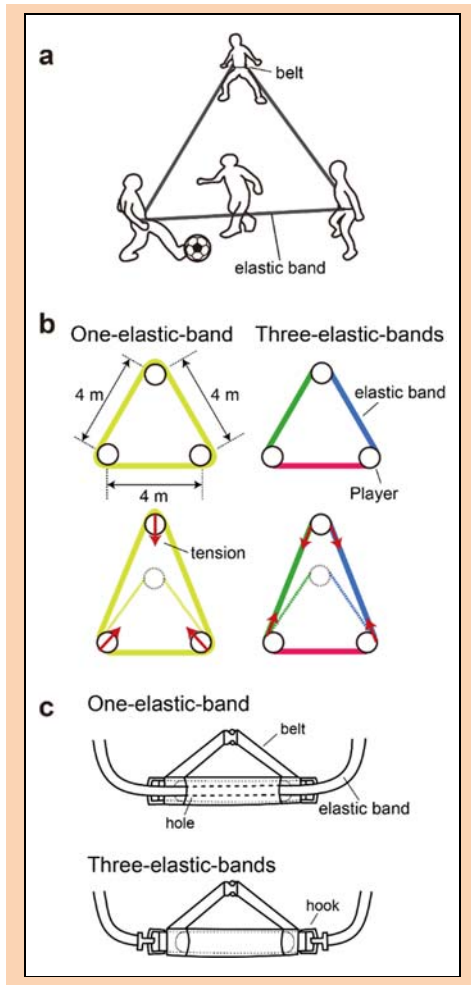


Figure 1. Schematic explanation of the functioning of the tools. **a:** Task in the conditions with tools. **b:** The one-elastic-band tool has one long elastic band. The three-elastic-bands tool has three elastic bands. The difference in color indicates the different bands. **(Top)** The three players are positioned in equilateral triangle. **(Bottom)** One player changes position dissolving the equilateral triangle. **c:** Structure of the belt for the one-elastic-band tool **(Top)** and three-elastic-bands tool **(Bottom)**.

The natural length without stretching of the elastic band in the one-elastic-band tool was 13.5 meters. This length was defined as the perimeter of the largest equilateral triangle the three players could form without stretching the band. This length was selected after determining the suitable distance between two players in this task to be

about 4 meters, in addition to an average of 0.5 meters to allow for each player’s width. When one player moves outside of the equilateral triangle’s position and the two players stay in the same position, the physical tension works on the center of the backs of all the three players (as shown by the arrows in Figure 1b, on the left).

The three-elastic-band tool was composed of three elastic bands with natural lengths of 4 meters. Therefore, when three players are placed in an equilateral triangle consisting of 4-meter-long sides, there is no physical tension. When one player moves outside the area of this triangle and the other two players stay in the same position, there is tension in the two elastic bands connected to the moving player but not in the other band (as shown by the arrows in Figure 1b, on the right). This means that the forces from the bands would only work in the direction of the changing distance between the two pairs of adjacent players. In other words, if the distance between players is maintained at the natural length, there is no force being exerted (the band indicated in the base of the triangle in Figure 1b, on the right).

Procedures

All groups performed three trials in each of the three conditions (Table 1). The duration of each trial was 60 seconds. When the task was interrupted owing to the ball going out of the play area, another ball was immediately passed to one of the attacking players by a researcher. The intervals between trials were about 3 minutes long. First, all groups performed the task under the control condition. Then, the groups alternately and randomly performed the task under the one-elastic-band condition and the three-elastic-bands condition.

The movement of all the participants during all the trials was captured by four infrared cameras (OptiTrack Prime 17W, Natural Point, Inc., Corvallis, OR, USA), operated at 120 Hz, and 75 mm markers were placed on the top of each players’ head. In this study, we analyzed the two-dimensional coordinates of the players’ positions in the field of play. One digital video camera, operating at 60 Hz, was used to record the ball movement.

Data analysis

We analyzed three types of dependent variables for verifying the effectiveness of tools among three different band conditions. These analyses were performed using MATLAB R2017b (The MathWorks, Inc., MA, USA).

Ball passing frequency. Ball passing frequency was the mean value, among all trials, of the absolute frequency of ball passes in each trial. This variable was calculated by notational analysis using the video captured by digital video camera.

Table 1. Trial order of each group in performing all the three experimental conditions.

Group	Motor Ability	Age (Mean)	Trial order								
			1	2	3	4	5	6	7	8	9
A	Low	9.7	Ctrl	Ctrl	Ctrl	1B	3Bs	1B	3Bs	1B	3Bs
B	Low	12.0	Ctrl	Ctrl	Ctrl	1B	3Bs	1B	3Bs	1B	3Bs
C	High	9.7	Ctrl	Ctrl	Ctrl	3Bs	1B	3Bs	1B	3Bs	1B
D	High	11.7	Ctrl	Ctrl	Ctrl	3Bs	1B	3Bs	1B	3Bs	1B

Ctrl, 1B, and 3Bs indicate the control, one-elastic-band, and three-elastic-bands conditions, respectively.

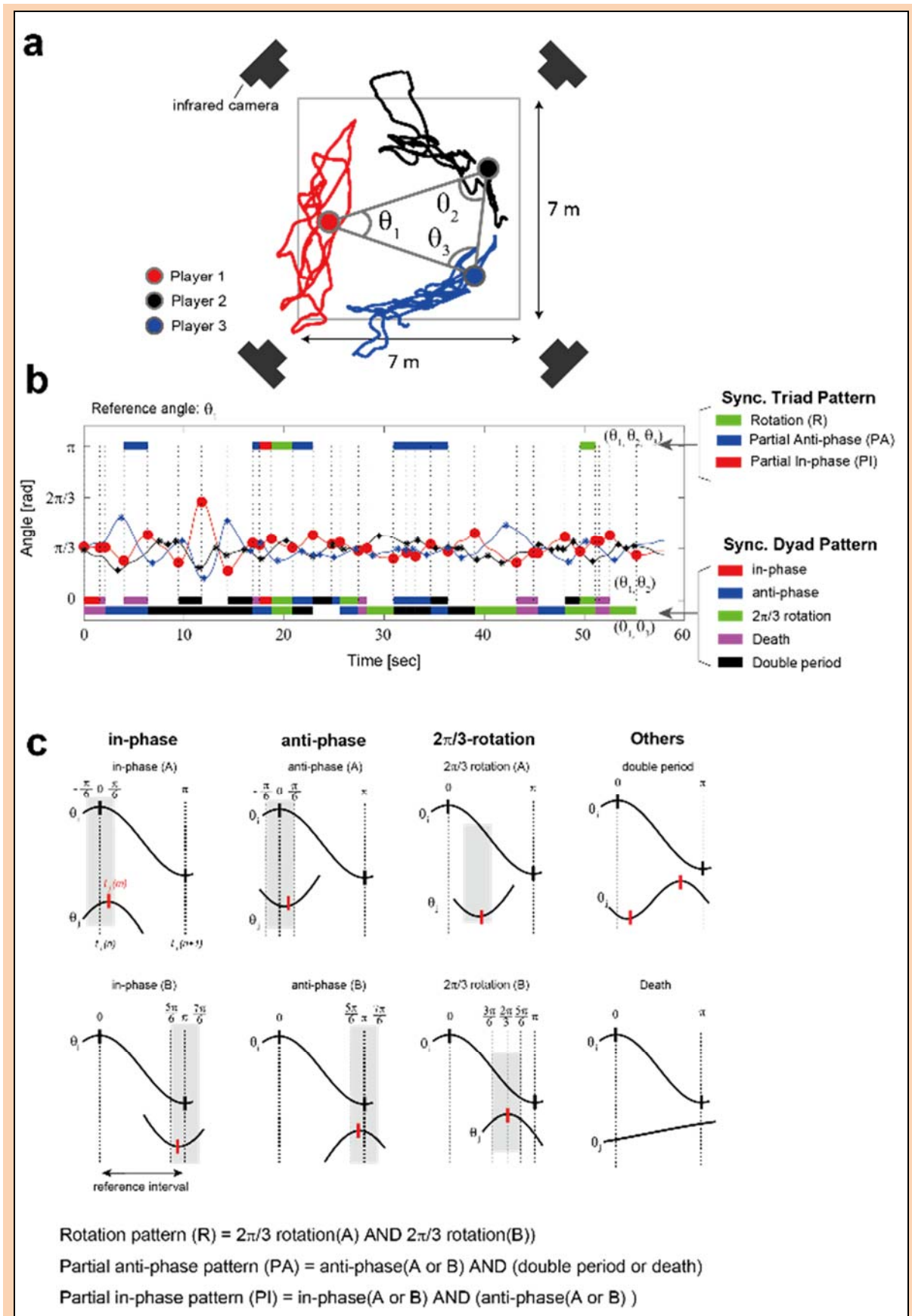


Figure 2. Procedures for data collection and data analysis. **a:** Experimental set-up. Trajectories indicate examples of the two-dimensional coordinate trajectory in the experimental task for the attacking players. **b:** Example of angle time series and the detection of the synchronized (dyad and triad) patterns. **c:** Categories of dyad synchronized pattern that originated the triad patterns (see text).

Inner angles. The frequency and amplitude or inner angles (θ_1 , θ_2 , and θ_3) in a triangle were measured using the two-dimensional coordinate position data of the three players (Figure 2a). First, we reduced the noise of the two-dimensional coordinate position data using a fourth-order Butterworth low-pass digital filter without phase shift. The optimum cut-off frequencies of this filter were calculated for the two-dimensional coordinate data of each player by means of residual analysis (Winter, 2004). The cut-off frequencies ranged from 0.49 to 0.88 Hz. Time series of the three inner angles were calculated, and the peak and valley points for the time series of each angle were detected using a peak detection algorithm (“peakdet” function in MATLAB). Peaks and valley were identified when adjacent points changed more than the 3% threshold of the standard deviation of each angle’s time series. In each condition of every group and in every trial, the mean frequency of the inner angles was used to calculate the following variables: (1) the number of peaks and time duration of the trial, (2) the mean frequency of three inner angles, and (3) the mean of the three trials. Moreover, the mean amplitude of inner angles was calculated by defining the range between the maximum and the minimum angle from the peak and valley points of each of the three inner angles in every trial.

Synchronized triad pattern. The computation of the variable synchronized triad patterns was based on the sum of the durations in each of the three main patterns: R pattern, PA pattern, and partial in-phase (PI) pattern. These were calculated as described in previous studies (Yokoyama and Yamamoto, 2011; Yokoyama et al., 2018). In short, the reference angle (θ_r) was first selected from the three angles. The interval was defined as the difference between adjacent peak and valley in reference angle (Figure 2c). Phase differences between the reference angle and the two other angles (θ_r , θ_i) (θ_r , θ_j) were also calculated. These two-phase differences, which indicated the dyad patterns, were classified into five patterns; in-phase, anti-phase, $2\pi/3$ rotation, death, and double period. Based on the combinations of the two-phase differences, we evaluated whether or not the three inner angles during the reference interval were synchronized and what type of pattern existed: an R pattern, a PA pattern, or a PI pattern (Figure 2b). When both dyad patterns showed $2\pi/3$ rotation, the synchronized triad pattern was defined as the R pattern. When one dyad pattern was the anti-phase pattern and another dyad showed either the death or double period, we defined the triad pattern as PA pattern. When one dyad pattern was the in-phase pattern and another dyad showed the anti-phase pattern, we defined the triad pattern as PI pattern. Finally, the duration of each synchronized triad pattern for all trials of every condition was calculated.

Statistical Analysis. We compared the three conditions (the control, one-elastic-band tool, and three-elastic-bands tool conditions) for the four dependent variables using repeated measures ANOVA and the Tukey honest significant difference test. These statistical analyses were performed using the R software package (version 3.4.0).

Results

We tested whether the band tool conditions affect the dependent variables (ball passing frequency, frequency and amplitude of inner angles in a triad, duration of synchronized triadic patterns) when compared with the control group. Further, we tested whether the one-elastic-band tool condition would show a higher frequency of the R pattern than the three-elastic-bands tool condition.

Figure 3a shows the results for ball passing frequency. The means for ball passing frequency for the control, one-elastic-band, and three-elastic-bands conditions were 16.92, 15.75, and 16.33, respectively. Repeated measures ANOVA revealed that there was no significant difference among these three conditions ($F(2,22) = 0.182$, $p = 0.835$).

Figure 4 shows an example of the time series of inner angles for the three conditions for one group. The dots on the time series represent the peaks and valleys that were used for the calculation of the frequency and amplitude of the inner angles. As shown in Figure 3b, the frequencies of the inner angles for the control, one-elastic-band, and three-elastic-bands conditions were 0.24 Hz, 0.27 Hz, and 0.27 Hz, respectively. Repeated measures ANOVA revealed significant differences among the conditions ($F(2,22) = 6.129$, $p = 0.007$). Post-hoc tests confirmed that there were significant differences between the control condition and both band tool conditions, respectively (control vs. one-elastic-band tool: $p = 0.009$; control vs. three-elastic-band tool: $p = 0.006$). Moreover, the amplitudes of the inner angles in the control, one-elastic-band, and three-elastic-bands’ conditions were 2.19 rad, 1.77 rad, and 1.43 rad, respectively (Figure 3c). Repeated measures ANOVA revealed a significant difference among the conditions ($F(2,22) = 6.672$, $p = 0.005$). Post-hoc tests confirmed that there was a significant difference between the control and three-elastic-bands conditions ($p = 0.002$). Neither of the other two differences was statistically significant (control vs. one-elastic-band tool: $p = 0.115$; one-elastic-band vs. three-elastic-band tools: $p = 0.255$).

Figure 3d shows the duration of the synchronized pattern, for each of the three conditions. Examples of time series of these variables are shown in Figure 4 with green, blue, and red lines that indicate the duration of the three identified patterns: R, PA, and PI, respectively. For the R pattern, the results in the control, one-elastic-band, and three-elastic-bands conditions were 3.83 seconds, 6.84 seconds, and 6.55 seconds, respectively. Repeated measures ANOVA revealed that there were no statistically significant differences among the three conditions ($F(2,22) = 2.741$, $p = 0.087$). With respect to the PA pattern, the mean value among groups in the control, one-elastic-band, and three-elastic-bands conditions were 22.46 seconds, 22.57 seconds, and 21.10 seconds, respectively. The repeated measures ANOVA revealed that there were no statistically significant differences among the three conditions ($F(2,22) = 0.275$, $p = 0.762$). Moreover, in terms of the PI pattern, the results for the three conditions were 8.88 seconds, 8.18

seconds, and 9.48 seconds, respectively, with no significant differences among these conditions ($F(2,22) = 0.307$, $p = 0.774$). Importantly, Figure 3d shows that the

duration of the PA pattern during the task was longer than the durations of both R and PI patterns in all conditions.

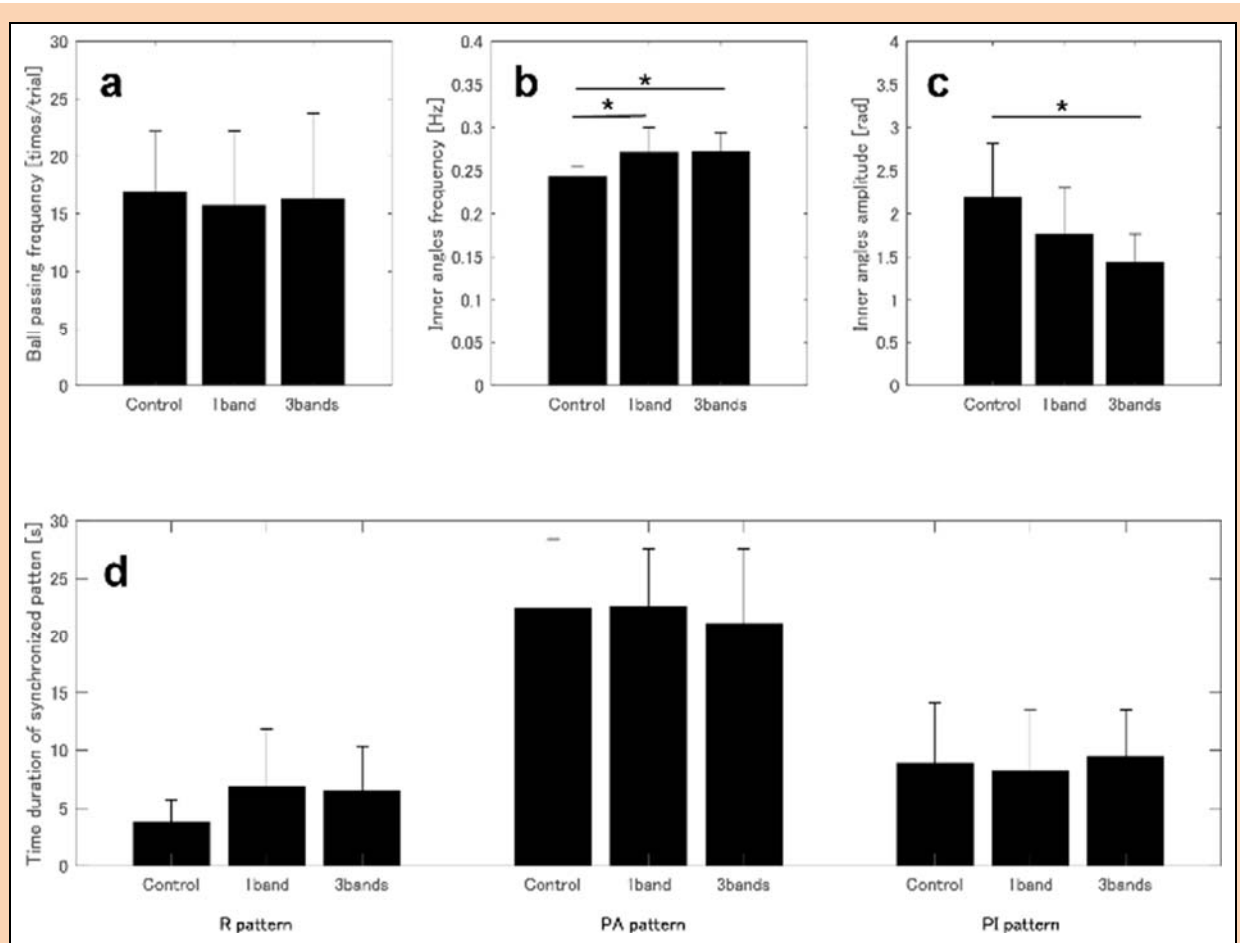


Figure 3. Mean value among conditions for each dependent variable. Error bars indicate the standard deviation of each variable among conditions. Asterisks indicate significant differences among conditions ($p < 0.01$). **a:** Ball passing frequency. **b:** Frequency of inner angles. **c:** Amplitude of inner angles. **d:** Duration of synchronized rotation (R), partial anti-phase (PA), and partial in-phase (PI) patterns.

Discussion

In this study, we compare two types of tools for enhancing triadic coordination. Previous research (Yokoyama and Yamamoto, 2011) treats triadic coordination as synchronization among three players, who are conceived as coupled oscillators. In particular, triadic coordination tends to show three patterns: synchronized R, PI, and PA patterns. In the present study, we assess how equipment such as the one-elastic-band tool and three-elastic-bands tool influences interpersonal coordination. We hypothesized that the physical linkage of the one-elastic-band tool would allow a better perceptual attunement than the three-elastic-bands tool and would be associated with different patterns of triadic coordination. However, this hypothesis was only partially supported.

The ball passing frequency data revealed that neither of the elastic tools increased the number of passes. This result is likely due to passing being rooted in intrapersonal skills (e.g., kicking or touching a ball) rather than interpersonal skills. This means that the ability to stop and pass the ball will not be enhanced by a tool for

interpersonal skill enhancement. Further research can test the independent contributions of intrapersonal and interpersonal skills by observing the acquisition process of these skills in a longitudinal experiment.

The results of the inner angles of the triangle formed by the players showed that: 1) their frequencies in both tool conditions were larger than the control condition and 2) their amplitude in the three-elastic-bands condition was lower than in the control condition. The high frequency of this variable suggests the high rate of change over time of the triadic formation. Therefore, this means when players use the three-elastic-bands tool or the one-elastic band tool, they can quickly adjust their triadic temporal organization. On the other hand, the amplitude of inner angles captures the stability of the spatial formation of the triadic coordination, indicating that the three-elastic-bands tool promotes a higher spatial stability than the other conditions.

One possible explanation for this finding about high frequency of angles is that with both elastic band tools, the physical force acting on the players is haptically perceived by them and, therefore, augments information about interpersonal coordination, facilitating the triadic temporal

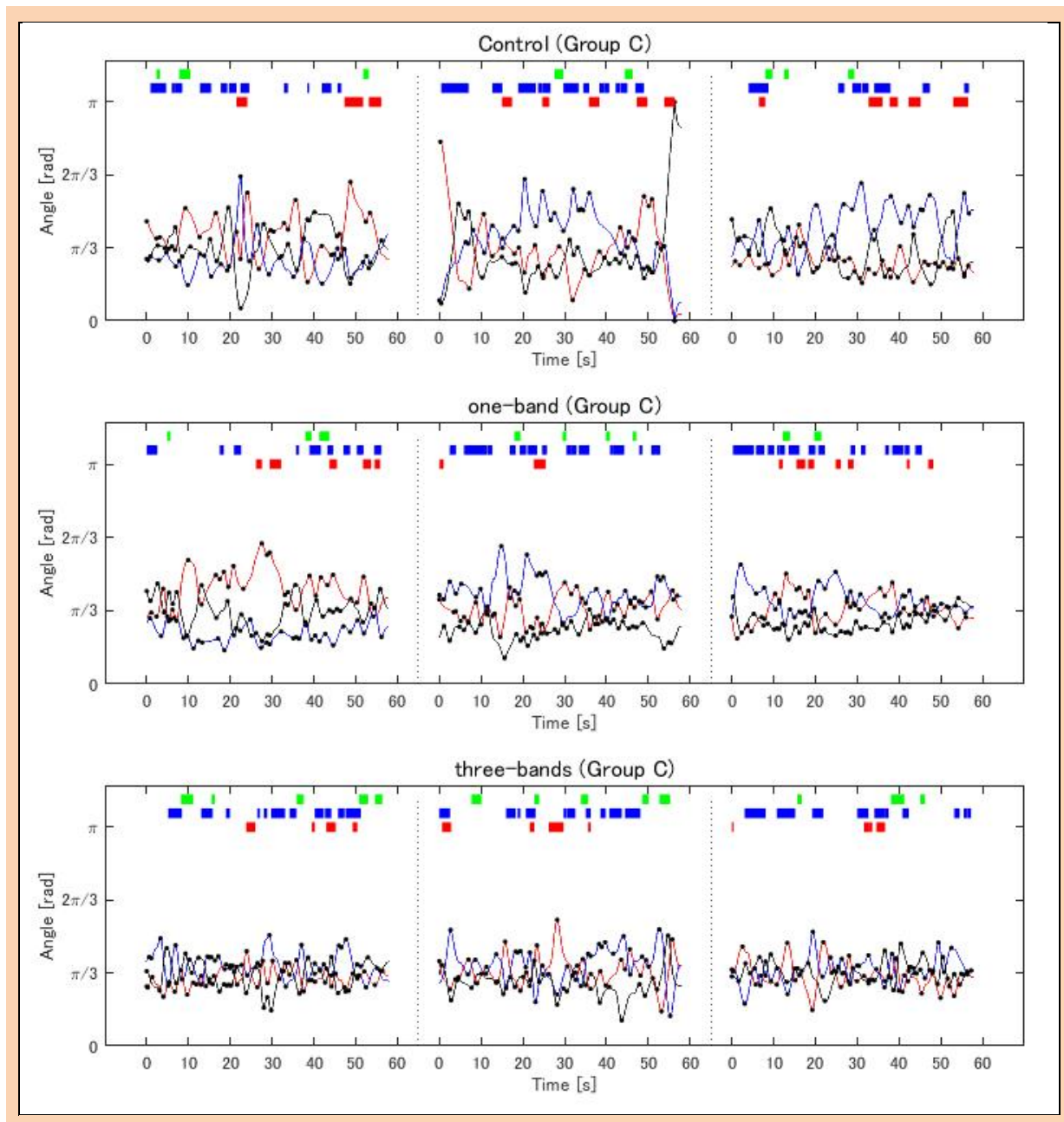


Figure 4. Example of time series of three trials of inner angles in a triangle formed by a triad. Dot points on each graph indicate the peaks and valleys in the time series. Green, blue, and red labels represent the time duration of synchronized rotation (R) pattern, partial anti-phase (PA) pattern, and partial in-phase (PI) pattern, respectively.

organization. On the other hand, in terms of the spatial formation indicating the amplitude of angles, the physical linkage with one or three bands was affected by the player's position. Especially, the physical force acted from the three-elastic-bands tool directly works on the player, and these forces adjust the interpersonal distances to the adjacent players (i.e., the three-band triadic structure tended to maintain the equilateral triangle). On the other hand, the physical force acted from one-elastic-band tool did not directly affect the spatial formation between the player and the adjacent players because the physical force acting on the player and haptically perceived by him/her

depends on the whole triad distance rather than on the adjacent interpersonal distances.

In addition to haptic perception, visual perception plays an important role. The elastic bands connecting players can be slackened when the adjacent interpersonal distance is reduced to less than 4 meters. The visual information about slackened band promotes the awareness of other players' positional displacement and affects the temporal organization and spatial formation in the triad. In particular, this is the case with the three-elastic-bands tool. However, the one-elastic-band tool does not show the tightness of the band because the physical strength of one-

elastic-band tool depends on the overall sum of triad distance. Therefore, even if the overall triad distance is shorter than its natural length, all the three distances among the players would be equally loose.

Therefore, in terms of applications to the training sessions, the three-elastic-bands tool may be more useful when stabilization of the spatial formation is needed during learning. The one-elastic-band tool may be more useful when adaptability is needed during learning (see Table 2 and Figure 5). In perceptual terms, these tools orient the players to more relevant affordances of the task, those that guide interpersonal coordination (Araújo and Davids, 2016). The subtle differences between these tools are that the three-elastic-bands tool perceptually attunes players to immediate displacement of their teammates, while the one-band tool attunes players to the triadic position as a whole. Thus, both tools enhance interpersonal coordination, although the three-elastic-bands tool is more useful at an earlier stage of learning, and the one-elastic-band tool is probably more informative in an intermediate level of learning (Araújo et al., 2019). This is, ultimately, a question for further research.

Considering the degrees of freedom that allow interpersonal coordination (Araújo et al., 2019; Bernstein, 1967), the elastic band tools treated in this study were connected between or among players and constrained their

degree of freedom of movement on the field of play (Figure 5). From this perspective, the elastic band tools would play a role for constraining the interpersonal degrees of freedom for the triad. In this case, the degrees of freedom are constrained according to the number of elastic bands, that is, the connections among the three players. This means that the three-elastic-bands tool provides the haptic and visual information of adjacent player's position and movement directly; whereas, the one-elastic-band tool informs players of the position and movement of the adjacent players indirectly, given that it informs players about the whole triad. As a result, the three-elastic-bands tool would be considered to constrain the interpersonal degrees of freedom more than the one-elastic-band tool (see Table 2 and Figure 5).

The perspective about degrees of freedom informs our understanding of the time evolution of complex systems with many components in interaction. Savelsbergh and colleagues argue that these degrees of freedom are not only physical components of the movement apparatus (e.g., muscles, tendons, and joints) but are also based on perceptual information from environmental object or other players, which shapes perceptual degrees of freedom (Savelsbergh et al., 2004). In line with this argument, we claim that the tools tested in this study offer possibilities for manipulating the interpersonal degrees of freedom in practice sessions.

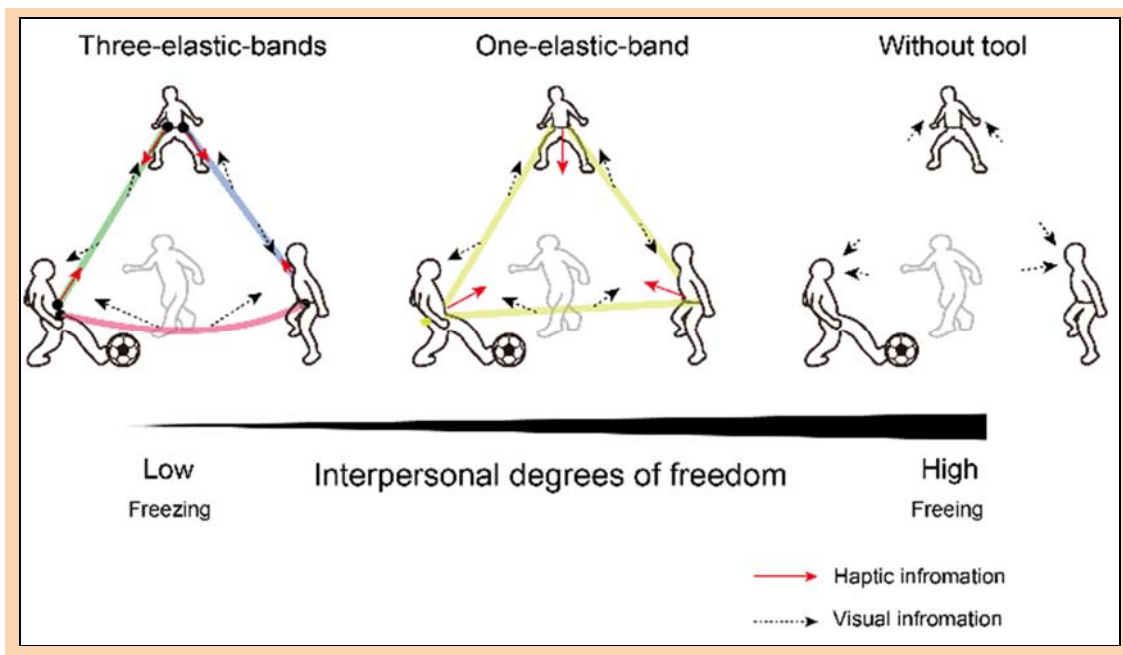


Figure 5. Schematic depiction of the different impacts in performance from the three-elastic-bands and one-elastic-band tools.

Table 2. Contrasting functional characteristics between the three-elastic-bands tool and the one-elastic-band tool.

	Three-elastic-bands	One-elastic-bands
Physical linkage type	3 bands connecting each 2 players	1 band connecting all 3 players
Haptic information (stretching band)	Independent two forces on hip depending on adjacent distances	Resultant one overall force on the back from the sum of triadic distance
Visual information (slacking band)	Information from two adjacent distances	Information from the whole triadic distance
Spatial formation	Stable equilateral triangle	Broken equilateral triangle
Temporal organization	High frequency	High frequency
Interpersonal degrees of freedom	Low	High

In the analysis of synchronized patterns, even though the elastic band tools influence the dynamics of coordination, none of the experimental conditions presented a preference for the PA or PI patterns. Moreover, there were no differences in the prevalence of the R pattern among conditions, our second hypothesis, where we expected the one-elastic-band tool to have a predominant R pattern than three-elastic-bands tool, was rejected. This can be explained based on the previously discussed results in which each tool seemed to present different ways to channel the emergence of the R pattern. As mentioned above, the three-elastic-bands tool can offer haptic and visual information but restricts interpersonal degrees of freedom, resulting in the spatial formation being kept around the equilateral triangle. This is not the case with the one-elastic-band tool. The one-elastic-band tool, with more interpersonal degrees of freedom, offers more global information about the triad, without direct information about the dyads. This suggests that one-elastic-band tool may facilitate more adaptive triad synchronization with greater freedom of movement, as it is not restricted to the equilateral triangle shape. Moreover, the haptic information provided by the one-elastic-band tool may induce lower symmetry breaking in triad coordination, increasing the prevalence of the R pattern (Yokoyama and Yamamoto, 2011; Yokoyama et al., 2018). In short, given the more restricted interpersonal degrees of freedom, the three-elastic-bands tool may not facilitate the R pattern as much as the one-elastic-band tool, which augments information about the “cooperative social force” among three players with higher interpersonal degrees of freedom. In terms of body movement degrees of freedom, it is known as the duality of degrees of freedom and degrees of constraint (Turvey, 2007; Turvey and Sérgio, 2014). The elastic band tool plays a role in facilitating harnessing interpersonal degrees of freedom.

In this study, we showed the efficacy of two types of equipment designed for improving the connection among players for triad coordination, by means of haptic and visual information. Previous studies on interpersonal (dyadic) synchronization focused on the linkage through visual information (Schmidt et al., 1990; Schmidt and Turvey, 1994; Richardson et al., 2007), as well as on a physical linkage through a mechanical object to stabilize dyadic synchronized patterns (Harrison and Richardson, 2009). Our results indicate that both sources of information increase triadic coordination. Such triadic coordination is realized without sharing the same CNS, as it was shown already in dyadic social motor coordination (Schmidt et al., 2011). However, triads in this study used not only visual information that is often demonstrated in dyadic (Schmidt and Richardson, 2008), but also haptic information. The elastic band offers the use of both sources of information, visual and haptic. According to Shaw (2001), there are four reference modes between self and other; the information about other independent of self (exterospecific information), information about other’s relation to self (expropriospecific control), information about self-independent of others (propriospecific information), and information about self’s relation to others (proexterospecific control).

This means that information for triadic movement would connect between and within self and others in cycles of perception-action couplings. In case of the present study, the physical coupling among players by the elastic bands play a role in highlighting information for the control of action between and within self and others for triadic coordination, using both haptic and visual means. These possibilities may help novice players utilize better sources of information for the task, facilitating both perception of the environment and sharing that environment perception with others (Araújo and Davids, 2016).

Specifically in sports with dyadic competitive interaction, such as one-on-one in basketball (Passos et al., 2008), boxing (Hristovski et al., 2006), rugby (Correia et al., 2011; Passos et al., 2008), martial arts (Okumura et al., 2012; Okumura et al., 2017), and tag games (Kijima et al., 2012), interpersonal distance between players is the critical parameter for decision-making, namely in the attack. Although interpersonal distance is also a critical parameter for the perception of affordances in triadic coordination, these affordances can be more local (i.e., the adjacent players) or global (the whole triad). The role of the tested elastic bands was to support the perception of affordances through haptic and visual information and to constrain the interpersonal degrees of freedom in order to realize triad synergies (Araújo and Davids, 2016; Silva et al., 2016).

Finally, we argue that there are clear applications for these tools for sports training and interpersonal motor learning. The tools tested in the present study offer augmented haptic and visual information for interpersonal coordination. The use of these tools can be included in practice sessions according to the development of the interpersonal skills of the players (Araújo et al., 2019). Based on our results, we suggest that players in the initial stage of learning team sport coordination may benefit from the use of the three-band tool. If they are able to maintain the triad spatial formation, then they may benefit from the use of the one-elastic-band tool. In this way, they evolve from freezing to freeing interpersonal degrees of freedom.

Conclusion

In this study, we hypothesized that players 1) would improve their triadic coordination skills with the help of a band tool, either with one-elastic-band or with three-elastic-bands tools; and 2) the one-elastic-band tool would facilitate the R pattern more than the three-elastic-bands tool. The results of an experiment involving 16 males under 12 years of age indicate that neither tool affects an increase in the synchronized R patterns. This result means that our second hypothesis was rejected. However, in terms of the triadic temporal coordination, both tools do facilitate players’ interpersonal coordination. Moreover, in terms of the spatial formation, the three-elastic-bands tool tends to adjust the players’ position to a stable equilateral triangle. These results were considered to support our first hypothesis. The practical tools designed to manipulate the interpersonal degrees of freedom tested in this study may new paths for understanding how to improve interpersonal coordination in collective sports.

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Key points

- We tested the two types of tools, a three-elastic-band tool and a one-elastic-band tool, both of which linked the three players together.
- Both elastic-band tools tend to facilitate temporal organization of triadic coordination.
- The three-elastic-bands tool tends to adjust the spatial formation to a stable equilateral triangle.
- Tools that physically couple the players manipulate interpersonal degrees of freedom; the three-elastic-band tool allows fewer interpersonal degrees of freedom than the one-elastic-band tool.

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