Olga Gali*
Sena Beste Ercan
Department of ICT
Pompeu Fabra University
Barcelona, Spain

Gray Atherton
Liam Cross
Department of Psychology
Edge Hill University
Ormskirk, UK

Batuhan Sayis
Department of ICT
Pompeu Fabra University
Barcelona, Spain

Pamela Heaton
Department of Psychology
Goldsmiths University
London, UK

Narcis Pares
Department of ICT
Pompeu Fabra University
Barcelona, Spain

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Mediating Interpersonal Synchronization in Children through a Full-Body Mixed Reality System: Analysis of the Pre-Interactive Mandala Experience

Abstract

Interpersonal entrainment (IPE), motor synchronization to a common rhythm, can be used to strengthen the ability to communicate and coordinate actions between citizens. Different studies show how children's and adults' behaviors changed positively by increasing their cooperation, helpfulness, and affiliation levels after performing activities in synchrony. However, those activities are often affected by the mediation of a researcher. This problem can be addressed by using new technologies such as mixed reality (MR) full-body systems. The aim of this study was to develop a playful MR pre-interactive (noninteractive visual/auditory cues) experience, the Mandala, to promote IPE. Sixty-six children were presented, in groups of four, with one of the conditions: async movements and ambient music (control) or sync movements accompanied by rhythmic (experimental 1) or ambient music (experimental 2). We analyzed the children's ability to follow the visual elements well (temporal pattern and precision), the good use of the interactive object, and their level of synchrony. The results show how the children followed the visual pattern well and accurately, used the interactive object as proposed, and achieved high levels of synchrony. We provided initial insights on how full-body MR systems can be used to promote IPE without an external facilitator.

1 Introduction

The successful and satisfactory development of human beings in society depends, among other things, on their ability to communicate and coordinate their actions with others (Bente & Novotny, 2020; Meyer & Hunnius, 2020). However, some people present important interpersonal communication and coordination difficulties. These skills could be strengthened by designing and developing technological systems that promote prosocial behaviors through interpersonal entrainment (IPE), a mechanism to promote more successful interactions (McNaughton & Redcay, 2020).

1.1 Interpersonal Entrainment

Interpersonal entrainment is explained as rhythmic synchronization that occurs in an intentional (conscious) or instructed manner such as while

*Correspondence to olga.gali@upf.edu.

dancing, walking, or singing (Koban et al., 2019; McNeill, 1995). To carry out these joint actions and obtain a common result between two or more people, it is required to coordinate the actions between the co-actors in time and space. What differentiates IPE from other forms of coordination is the joint synchronization of individuals to a common rhythm and the perception among co-actors (Bente & Novotny, 2020). Accordingly, it does not require the figures of leader and follower (Bente & Novotny, 2020). Sociocognitive studies show how judgments of social connectedness and relatedness improve when behavior is coordinated between two or more people (for a review, see Cross et al., 2019). On the other hand, studies of dynamic systems show the existence of two predominant modes of interpersonal coordination: in-phase and anti-phase synchrony (Miles et al., 2009). In-phase coordination refers to the coordination of movement with a relative phase relationship of 0° in which the coordinated rhythmic actions are at equivalent points in the movement cycle. In contrast, anti-phase coordination refers to coordinated movements that are opposite each other in the movement cycle, that is, with a relative phase relationship of 180°. In less stable phase relationships, the agents are said to be out-of-phase or in asynchrony. Both in and anti-phase synchronizations have been shown to produce the prosocial effects of IPE (Cross et al., 2016). Different studies showed how IPE is present in early infant–caregiver interactions with the postulation that it is a mechanism by which infants develop language skills (Delaherche et al., 2012; Feldman, 2007) and self-regulatory mechanisms (Feldman et al., 1999). They also showed how rhythmic synchronization of body movements is related to cooperation and perceived group entitativity, relational quality, rapport, and other social behaviors (Cross et al., 2019). One of the most studied impacts of IPE on social development is prosocial behavior. Prosocial behaviors are defined as voluntarily helping others and acting for the individuals in the group (Eisenberg et al., 1983).

The impact of IPE on prosocial behavior has been studied in both adults and children, with results showing positive effects in the early stages of development (Cirelli, 2018). In 14-month-old children, significantly greater helping behavior towards an experimenter was reported after synchronous movement with this person than in an asynchronous condition (Cirelli, Einarson, et al., 2014; Cirelli, Wan, et al., 2014). In addition to the adult–child social effects promoted by IPE, the social effects of IPE between pairs of children have also been investigated. Tunçgenç and Cohen (2018) showed the positive effects of IPE in children aged 4–6 years. Kirschner and Tomasello (2010), conducted a study with 4-year-old children where, in one condition, the children were singing and dancing together with the assistance of the researcher, while in the other condition, they were performing an asynchronous nonmusical exercise. The results demonstrated that music-making with dancing and singing together could foster social bonding and group cohesion between children, and ultimately increase cooperation and prosocial in-group behavior. Positive alterations by synchronous interactions in social attitudes have also been seen in children aged 8–9 (Rabinowitch & Knafo-Noam, 2015; Tunçgenç & Cohen, 2016). Atherton et al. (2019) have also shown that IPE can be utilized to reduce negative attitudes towards out-groups. Other work shows that these effects can persist outside of the lab for some time after the IPE manipulation (Cross et al., 2020).

1.2 Interpersonal Entrainment and Music

A way in which researchers facilitate the task of being in sync is through the use of rhythmic auditory stimulation. Thus, the visual stimulation is superimposed on the rhythm set by the auditory stimulus which can help stabilize the IPE (Bente & Novotny, 2020). The coupling is possible thanks to the characteristics of music and the abilities that only humans have to perceive all its elements. Among others, humans can perceive tempo, that is, the beats per minute of a song or sound. Therefore, when individuals listen to music, they can synchronize their bodily rhythms with those of the music by adjusting and adapting their phase and/or periodicity (Trost et al., 2017). Thus, entrainment between individuals or groups can be linked to an external pacemaker, such as the tempo of the music (Hardy &

LaGasse, 2013), when a joint action takes place (Stupacher et al., 2017).

1.3 Interpersonal Entrainment and Information and Communication Technologies

Although studies have shown the potential of IPE to promote more prosocial behaviors and greater connectedness, these are often mediated by a researcher (Rabinowitch & Knafo-Noam, 2015; Kirschner & Tomasello, 2010). Therefore, the coordination of the co-actors could be affected by the person who choreographs. This effect can be addressed through new technologies that allow the development of more engaging and dynamic therapies, learning experiences, and ecologically valid tools for children. They make it possible to develop MR interactive experiences where the physical space merges with the virtual space, allowing for simultaneous face-to-face navigation. The face-to-face interaction allows the individual to perceive the other co-actors, including their nonverbal communication such as facial expressions and body postures/gestures, while performing a collective activity. In Mora-Guiard et al. (2017), the potential of full-body MR systems was used to foster social initiations of pairs of children with and without autism spectrum condition (ASC). The mediation of social interactions took place without the need for a human facilitator. Results showed how the full-body MR system promoted the same levels of social initiations when compared to a LEGO play-based regular therapy (Crowell et al., 2020; Gali-Perez et al., 2021). This reflects the potential of information and communication technologies (ICT) to enrich experiences with their possibilities (Rinott & Tractinsky, 2022) such as mediating children without the need for a human facilitator. For example, Tryfon et al. (2017) used ICT to analyze children's ability to keep rhythm through an auditory stimulus. Another example is the Sync4All project (Varni et al., 2012). The authors used a mobile application to promote motor synchronization between users. Additionally, researchers such as Nalepka et al. (2017) used an interactive virtual environment to study the dynamic principles underlying human group coordination and human–machine interaction (Nalepka, Lamb, et al., 2019). A study by Tarr et al. (2018) also found that VR-mediated synchrony is capable of fostering prosociality.

On the other hand, Rinott and Tractinsky (2022) introduced dimensions of IPE that can be utilized to design interactive experiences: temporality, involvement of the interactive object, and entrainment stimuli. Temporality, in turn, has two attributes: temporal pattern and temporal precision. The temporal pattern is how identical the movements are (in phase, in counter phase, or one after the other) and the temporal precision is how tight the synchronization is. In the latter case, it is important to consider how latency can reduce the level of synchronization (Dabrowski & Munson, 2011). The second dimension, the involvement of the interactive object, can limit movements to a specific pattern by decreasing the degrees of freedom of movement, which makes synchronization easier. The entrainment stimuli dimension is defined by the type of pacing source that leads to synchronization, since synchrony can be guided by an external pacer such as sound and/or visual stimulation or by people creating their own shared rhythm.

1.4 Research Questions and Hypotheses

With technological improvements, different technological tools have been created to develop more engaging, dynamic therapies and learning experiences for children. New technologies such as MR have allowed the development of such systems, in which multiple children can "play" in a full-body interaction environment without the need for a human facilitator.

In consequence, the objective of the present study was to develop a playful pre-interactive experience in an MR system that uses the benefits of full-body interaction to promote IPE. By "pre-interactive," we mean that we have developed a system between therapist/researcher-guided activities and fully interactive experiences. The reason is that we first wish to analyze how the system can substitute the human in the mediation process, and later analyze how the system can propose real-time interactive and adaptable experiences. Therefore, in this version, rather than having the assistance of the researcher, it was the system that guided the experience through noninteractive visual and auditory cues. Specifically, we addressed the research question: is it possible to mediate the movement of four children through an MR system to promote their interpersonal entrainment without the need for a human facilitator? For that, children 8–10 years old participated in a 6-minute virtual playful experience. Under the same actions to be performed (reach virtual elements by an interactive object) and the final objective of building a Mandala, the children interacted with the system and with the co-actors through synchronous movements (experimental conditions), accompanied by rhythmic or ambient music, or with asynchronous movements (control condition) accompanied by ambient music. To understand the effectiveness of the pre-interactive experience in promoting good synchronized activity we used the dimensions defined by Rinott and Tractinsky (2022): temporality, the effect of the interactive object used, and the entrainment stimuli. Therefore, the hypotheses are:

H1. Users can follow the temporal pattern to adequately catch the virtual elements (glitter clouds) in all conditions.

H2. The temporal precision of children's movements towards the virtual elements (glitter clouds) and the instant at which the glitter cloud appeared is well adjusted in all conditions.

H3. The temporal precision of children's walking and the instant at which the glitter clouds start and end the transition is well adjusted.

H4. The tracked, luminous, handheld object ("interactive object") is used as proposed in all conditions.

H5. The stimuli used (visual and auditory-visual) in the synchronous conditions lead to good levels of synchrony between the users and the system, and therefore between the users.

2 Research Methods

2.1 Participants and Ethics

Out of a total sample of 66 children, 48 children were included in the study (22 girls, $M_{\text{age}} = 8.5$ years, $SD_{\text{age}} = 0.51$ years; 22 boys, $M_{\text{age}} = 8.32$ years, $SD_{\text{age}} = 0.57$ years; 4 bi-gender, $M_{\text{age}} = 8.25$ years, $SD_{\text{age}} = 0.5$ years). A total of 18 children were not included in the final study sample because the group either did not have a total of 4 members (6 children affected), because the interactive experience could not be carried out properly due to external distractions (4 children, one group affected), or because the video recordings taken during the interactive experience performance did not allow adequate coding due to visualization issues (8 children, two groups affected). They were recruited from the 3rd- and 4th-grade groups of a local primary public school in Barcelona (Catalonia, Spain). Each session consisted of a group of four children, with neither sex nor gender being a factor in the grouping. Children were randomly assigned to each group considering they did not have strong relationships. As in Kirschner and Tomasello (2010), children were familiar with each other to recreate a situation analogous to traditional small-scale societies.

The study was approved by the university's ethics board. We gathered written informed consent forms from the legal representatives as well as oral assents from the children on the day of the session. All data has been kept anonymous and used only in an aggregated format.

2.2 General Experimental Design

The duration of a user trial was approximately 40 minutes for each group (4 children), consisting of four stages: (1) pre-test questionnaire; (2) performance of the joint task in the pre-interactive full-body MR system; (3) post-test questionnaire; and (4) behavioral tests to assess social bonding and prosociality. The present study focuses its analysis on the second stage: the performance of the joint task in the pre-interactive full-body MR system. In Cross et al. (2022), we analyzed the effect of the pre-interactive experience on prosociality and social bonding behaviors (stage four).

In stage 1, children answered a short questionnaire about group cohesion–perceived relationship, age, gender, and music and dancing abilities. In stage 2, children carried out a joint task in a full-body interactive environment designed to foster IPE. The groups of children were pseudorandomly (each group class, three

Figure 1. *The full-body MR pre-interactive Mandala experience. The image shows how the experience mediates the actions of four children to synchronize their movements (experimental condition).*

in total, was assigned to one condition) assigned to one of the joint task types (independent variable): synchronous movements accompanied by rhythmic music ("Experimental 1" condition, 3 groups assigned, 12 children); synchronous movements accompanied by nonrhythmic ambient music ("Experimental 2" condition, 5 groups assigned; 20 children); and asynchronous movements accompanied by nonrhythmic ambient music ("Control" condition, 4 groups assigned, 16 children). The study followed a between-subjects design. (See section 2.3 for a detailed explanation of the pre-interactive experience and conditions.) Immediately after, in the same room, children answered the post-session questionnaire, stage 3, structured in two sections: (i) user-experience questions and (ii) group cohesion–perceived relationship questions. Behavioral tests, stage 4, were carried out in a room adjacent to the interactive MR space. In this stage, physical proximity was used as an indicator of social closeness and bonding, and the willingness of children to share their resources with others was used as an indicator of prosociality. For the first behavioral test, we used an adaptation of the proxemic test called Island Game validated in Tunçgenç and Cohen (2016) with children. For the second one, we used an adaptation of the decision-making game validated in Rabinowitch and Meltzoff (2017) with children.

2.3 The Full-Body Mixed Reality Pre-Interactive Experience: The Mandala

The pre-interactive experience was carried out in a 6 × 6 meter floor projection MR system where a full-body interactive environment was designed to foster IPE (see Figure 1). This MR system consists of a graphics workstation, two HD projectors generating a 1920 × 1920 pixel floor projection, a HiFi spatially panned sound system, and our in-house, computer vision–based tracking system that uses luminous "interactive objects." An interactive object is a handheld, battery-powered, luminous pointer, embodied as a circular physical object (20 cm diameter) with LED lights around its perimeter that give it a distinct color from the rest. This helps the system identify each child, having a different color assigned to each (red, green, blue, and purple). The application of the experience was developed in Unity and C#. In all conditions, the children had to build a virtual Mandala (abstract geometric design/pattern, see Figure 1 for the pattern used) situated at the center of the interactive space. Each child was placed in one of the corners of the interactive space (dubbed *stations*) to "interact" with the system and to be able to perceive the others' movements. In each station, children found three empty circles in front of them (left, front, right) in which a group of particles (*glitter cloud*) appeared in sequence with an interval of four seconds: left, front, and right, with a pause after every set of three events. It was explained to the children that they had to touch the glitter clouds through an interactive object. In other words, they had to move the interactive object they were holding with their two hands from their position (situated in front of the three circles) to the glitter cloud that appeared in one of the circles: a back-and-forth movement was performed with both arms. After one second, these glitter clouds were transformed into a glitter river that flowed to the center of the Mandala and contributed to its colorful construction. In addition, to encourage the children's motivation, transitions were made from one station to the next one, in a counterclockwise rotation, after a certain number of interactions with the glitter clouds, fostering a joint transition. In these transitions, the children followed a glitter cloud that showed them where to go next. Once they reached the new station, the three-circles cycle (new round of interactions with the glitter clouds) was repeated. Children performed a total of 8 rounds. The color of the glitter cloud to build the Mandala was the same for all interactions and all players in each round (see Table 1 for detailed information). Children interacted asynchronously, accompanied by non-rhythmic ambient music, with their glitter clouds in the Control condition. Asynchronous interaction meant that the glitter clouds appeared in the corresponding circle at a different time for each user; there were never two or more children interacting simultaneously. In contrast, in the experimental condition, they all performed their interactions in sync, that is, the four players interacted with the glitter cloud at the same time. In the experimental condition, synchronous movements were accompanied by rhythmic music (Experimental 1) or by nonrhythmic ambient music (Experimental 2). All conditions lasted six minutes and entailed the same difficulty, since children achieved the same final goal of building the virtual Mandala. There was direct interaction between the user and the system and indirect interaction between users as the actions of one child were perceived by the others.

Table 1. *Information on the Colors and Number of Movements Performed in Each Round of the Joint Task*

Round(s)	Number of interactions	Three-circles cycles	Color of the glitter
1–2	9	3	Yellow
3–5	6	2	Blue
6–7	6	2	Orange
8	3	1	Blue

2.4 Video Coding and Reliability

To analyze the performance of the joint task in the MR system, two researchers coded the recorded videos of this activity through the BORIS software, version 7.13.6 (Firard & Gamba, 2016). It was coded in frame-by-frame mode, 59.94 frames by second (FPS). Percentage agreement and Cohen's Kappa were run for each category to determine the level of agreement between the two coders. A detailed definition of each category can be found in Table 2.

For the temporal pattern of catching the glitter cloud, we obtained a Kappa score of $k = 0.77$ and an agreement percentage of 98.04%; for the temporal precision to catch the glitter clouds, we obtained a Kappa score of $k = 0.80$ and an agreement percentage of 94.12%; for the transition temporal precision, we obtained a Kappa score of $k = 0.96$ and an agreement percentage of 95.31%; and for the interactive object usage (type of movement) we obtained in both a Kappa score of

Table 2. *Video Coding Categories with Definitions*

Behavior	Event	Definition
Temporal pattern to catch the glitter cloud	Correct	The interactive object is moved toward the circle with the glitter cloud.
	Incorrect	The interactive object is moved toward an incorrect circle, without the glitter cloud.
	Correct after incorrect	The interactive object is moved toward the correct circle after an incorrect one.
	Unrelated	The user movement performed with the interactive object is not related to the circles.
	No movement	There is no movement performed.
Temporal precision to catch the glitter cloud*	Before	The instant the user reaches with the interactive object the circle with the glitter cloud is before the instant the glitter cloud appeared inside the circle.
	Similar	The instant the user reaches with the interactive object the circle with the glitter cloud is performed within the two seconds after the glitter cloud appeared inside the circle. The two seconds window was based on previous studies (Bucsuházy & Semela, 2017; Iida et al., 2010; Kiselev et al., 2009).
	After	The instant the user reaches with the interactive object the circle with the glitter cloud is performed two or more seconds after the glitter cloud appeared inside the circle.
Temporal precision of the transition starting**	Before	The instant the user starts moving one of the legs to walk is before the instant the glitter cloud starts moving.
	Similar	The instant the user starts moving one of the legs to walk is performed within the two seconds after the glitter cloud starts moving.
	After	The instant the user starts moving one of the legs to walk is two or more seconds after the glitter cloud starts moving.
Temporal precision of the transition ending**	Before	The instant the user arrives at the new station is before the instant the glitter cloud arrives at the station.
	Similar	The instant the user arrives at the new station is within the two seconds after the glitter cloud arrives at the station.
	After	The instant the user arrives at the new station is two or more seconds after the instant glitter cloud arrives at the station.

Table 2. *Continued.*

Behavior	Event	Definition
Object involvement	Proposed	The interactive object is used as proposed: moving it back and forth to "catch," reaching the circle with the glitter cloud.
	Different	Throwing the object toward the glitter cloud Touching the floor with the interactive object Rather than moving the hand and foot, jumping inside the circle Moving only the foot and not the interactive object

*The temporal precision for "catching" the glitter cloud was calculated as the time difference between the moment the glitter appeared inside the circle and the moment the user placed the interactive object on the glitter cloud (user movement), that is, reached the circle with the glitter cloud.

**The temporal precision for the start of the transition was calculated as the time difference between the moment when the user moves the leg to start walking and the moment when the glitter cloud starts to move. At the end of the transition, the time difference was calculated between the moment the user stopped walking and arrived at the new station and the moment the glitter stopped moving.

k = 1 and an agreement percentage of 100%. We would like to highlight that the usual validity ranges of Kappa scores are typically used for coding based on counting occurrences of events within a specified video segment. However, in our case coding is referred to time-stamped events, which ask for much greater precision between coders, since they have to match each and every event. Therefore, the agreement between the two coders may be considered exceptionally high and sufficient to achieve interrater reliability.

2.5 Entrainment Stimuli: Synchronicity Level Analysis

The pre-interactive experience promoted synchronization through external stimuli (external entrainment): unimodal (visual) or bimodal (visual and auditory) (for details, see section 2.3).

We evaluated the synchrony level of the movements made by players and categorized as "Correct" and "Similar" in the experimental pre-interactive experiences (Experimental 1 and Experimental 2 conditions). That is, we considered the movements of the players that were in synchrony with the system (user–system synchrony). As the pre-interactive experience guides the movements, a good synchronization of the player with the system will result in good synchronization between the players. Therefore, we calculated the proportion of movements out of the total number of movements for each possible synchronization option between players: four players synchronized with the system (very high sync), three players synchronized with the system (high sync), two players synchronized with the system (moderate sync), and one or zero players synchronized with the system (no synchronization).

3 Results

The participants were all different individuals tested in one of three different conditions: sync movements accompanied by rhythmic music (Experimental condition 1); sync movements accompanied by nonrhythmic ambient music (Experimental condition 2); and async movements accompanied by nonrhythmic ambient music (Control condition). Descriptive analysis was used to assess the synchronizing activity (temporal pattern and precision) and triggers and conditions (object involvement and entrainment stimuli) dimensions. Additionally, we ran the independent-samples Kruskal-Wallis test to assess if there were significant differences between conditions.

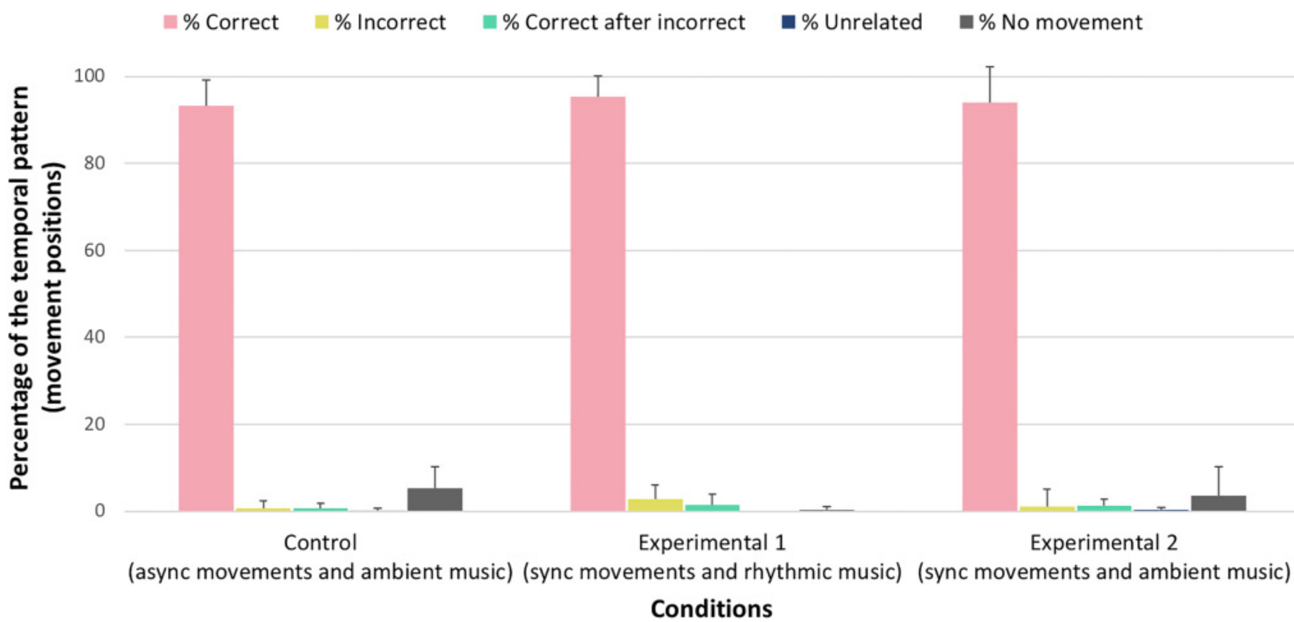

Figure 2. *Percentage and error bars of the temporal pattern (movement positions) for each condition: Control, Experimental 1, and Experimental 2.*

3.1 Synchronizing Activity Dimension

3.1.1 Temporal Pattern. All the results from the temporal pattern of the players' movement to catch the glitter cloud are shown in Figure 2. Children showed higher levels of "correct movements" in all conditions compared to the other movement positions. The "correct movement" is achieved in the Experimental 1 condition with the highest percentage ($M = 95.43$, $SD = 4.68$), followed by the Experimental 2 condition ($M = 93.92$, $SD = 8.39$) and the Control condition ($M = 93.31$, $SD = 5.89$). In addition, and looking in more detail, when the three conditions were compared regarding the total percentage of correct movements, there was no significant difference between them ($H(2) = 1.452$, $p = .484$).

3.1.2 Temporal Precision. All the results from the temporal precision of the players' "correct movements" and the transitions associated with the joint task are shown in Figures 3 and 4.

3.1.2.1 Temporal Precision to Catch the Glitter Clouds. The percentage for having a Similar movement was the highest in the Control condition ($M = 86.71$, $SD = 15.09$), followed by the Experimental 2 condition ($M = 86.54$, $SD = 18.29$) and the Experimental 1 condition ($M = 85.30$, $SD = 8.65$). When the three conditions were compared in the total percentage of Similar movements, there was no significant difference between them ($H(2) = 3.049$, $p = .218$).

3.1.2.2 Temporal Precision for Transition. For the start of the transition, the percentage of moving Similar with the particle was the highest in the Experimental 1 condition ($M = 85.42$, $SD = 13.93$), followed by the Experimental 2 condition ($M = 85$, $SD = 9.6$) and the Control condition ($M = 75.78$, $SD = 20.14$). Additionally, for the end of the transition, the percentage of Similar movement was the highest in the Experimental 2 condition ($M = 84.38$, $SD = 23.25$) followed by the Control condition ($M = 72.66$, $SD = 22.33$) and the Experimental 1 condition ($M = 64.58$, $SD = 27.09$). In addition, and looking in more detail, when the three conditions were compared, there was no significant difference between them in the total percentage of Similar movements when the transition started ($H(2) = 2.606$, $p = .272$). However, when the three conditions were

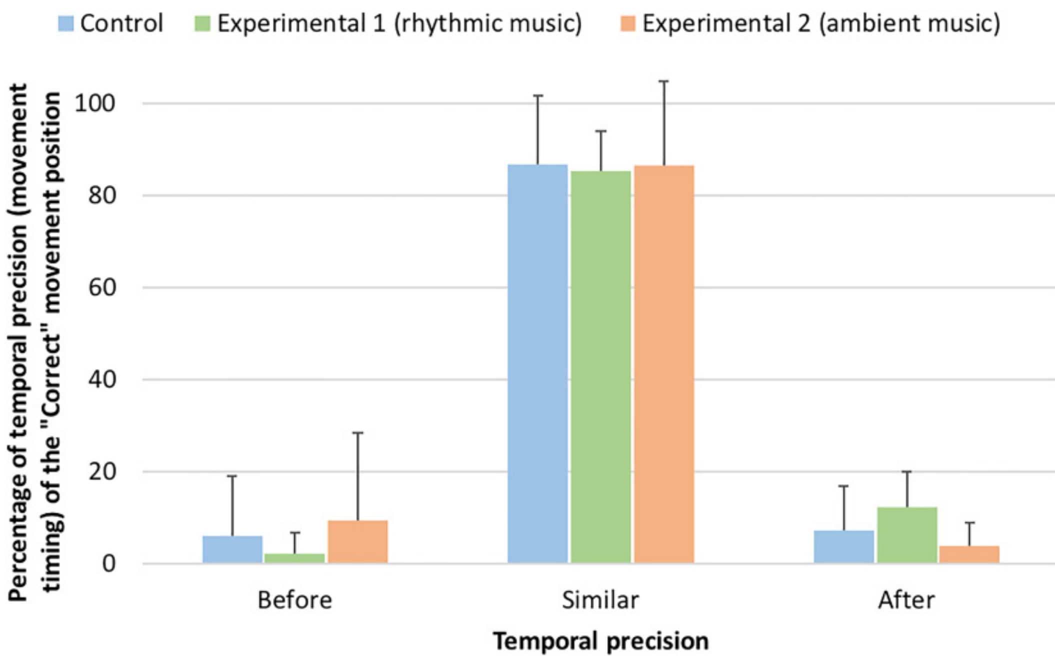

Figure 3. *Percentage and error bars of the temporal precision (movement timing) of the Correct movement position for each condition: Control (async movements and ambient music), Experimental 1 (sync movements and rhythmic music), and Experimental 2 (sync movements and ambient music).*

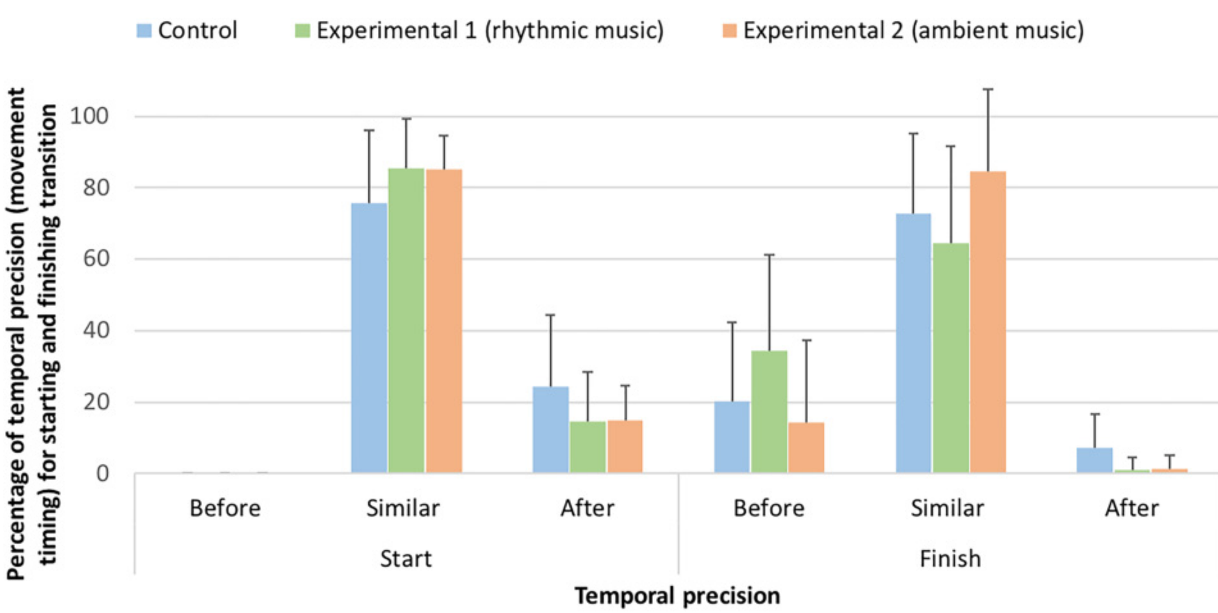

Figure 4. *Percentage and error bars of temporal precision (movement timing) for starting and finishing the transition for each condition: Control (async movements and ambient music), Experimental 1 (sync movements and rhythmic music), and Experimental 2 (sync movements and ambient music).*

Table 3. *Descriptive Data of the Object Involvement for Each Condition: Sync Movements Accompanied by Rhythmic Music (Experimental 1) and Ambient Music (Experimental 2) and Async Movements (Control)*

		Conditions					
		Experimental 1		Experimental 2		Control	
		Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
Movement type	Proposed (%)	98.04	3.13	93.53	9.35	83.42	15.14
	Different (%)	1.63	2.75	2.75	7.8	11.12	14.41
Different Movements	Throwing object (%)	0	0	0	0	0.71	2.26
	Touching the floor with the object (%)	0	0	100	0	85.45	17.08
	Jumping inside the circle (%)	75	50	0	0	9	17.78
	Moving only the foot (%)	25	50	0	0	4.83	8.91

NOTE. $N = 48$ in total ($n = 12$ in Experimental 1, $n = 20$ in Experimental 2, and $n = 16$ in Control condition).

compared in the total percentage of Similar movements when the transition ended, there was a significant difference between them ($H(2) = 6.736$, $p = .034$). The post hoc analysis revealed almost statistically significant differences in the percentage of Similar movement between the Experimental 1 condition and Experimental 2 condition ($p = .054$), but not between the Control condition and the Experimental 1 ($p = 1.00$) and Experimental 2 ($p = 0.159$) conditions.

3.2 Triggers and Conditions Dimension

3.2.1 Object Involvement. All the results from the usage of the interactive object are shown in Table 3. Children moved as proposed more times, over 80%, than a different movement in all conditions. When the three conditions were compared, there was a significant difference between them in the total percentage of "proposed" movements ($H(2) = 10.075$, $p = .006$). Pairwise comparisons were performed using Dunn's (1964) procedure with a Bonferroni correction for multiple comparisons. The post hoc analysis revealed statistically significant differences in the percentage of proposed movement between the Experimental 1 condition ($M = 98.04$, $SD = 3.13$) and Control condition ($M = 83.42$, $SD = 15.14$, $p = .007$), but not between the Experimental 2 condition ($M = 93.53$, $SD = 9.35$) and Control ($p = 0.071$) and Experimental 1 ($p = 0.8$) conditions. Of the movements done differently than proposed, 100% and 85.45% ($SD = 17.08$) were of placing the interactive object on the floor to touch the glitter cloud in the Experimental 2 and Control conditions, respectively. In addition, in the Experimental 1 condition, 75% ($SD = 15$) of actions were jumping inside the circle where the glitter cloud appears.

3.2.2 Entrainment Stimuli: Synchronicity Levels. All the results about the levels of synchronicity obtained in each experimental condition are shown in Figure 5. The percentage of achieving "very high sync" was the highest, compared to the other synchronization levels, in both the Experimental 1 condition ($M = 63.40$, $SD = 19.64$) and the Experimental 2 condition ($M = 46.27$, $SD = 26.58$), followed by the percentage of achieving "high sync" in both the Experimental 1 ($M = 30.07$, $SD = 14.85$) and the Experimental 2 ($M = 29.41$, $SD = 8.20$) conditions. Due to the small number of groups in each condition (three groups in Experimental 1 and five groups in Experimental 2), the independent-sample Kruskal-Wallis test was not conducted.

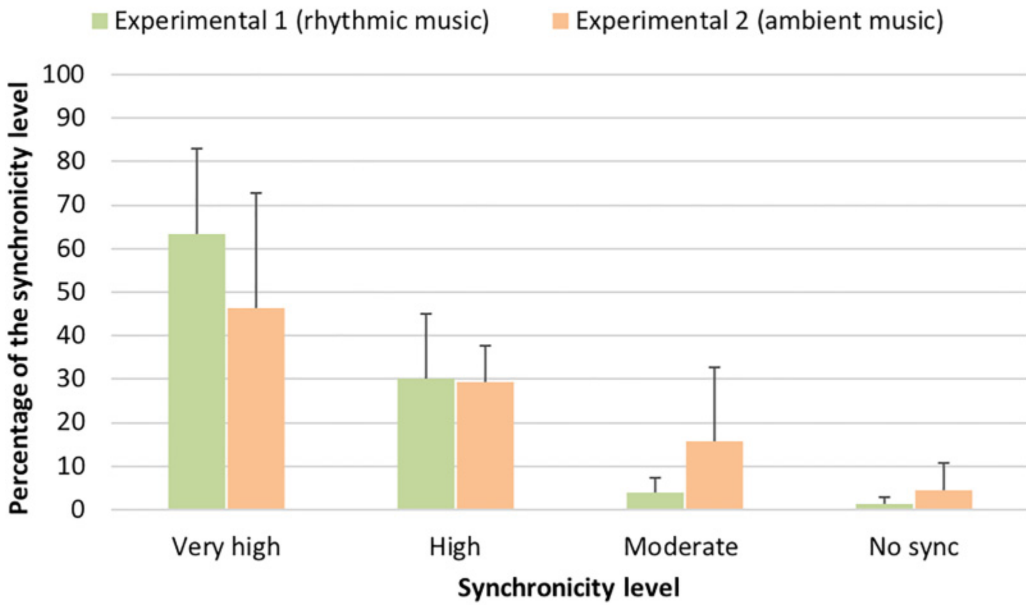

Figure 5. *Percentage and error bars of the synchronicity level for the experimental conditions: Experimental 1, sync movements and rhythmic music, and Experimental 2, sync movements and ambient music.*

4 Discussion

The present study aimed to analyze whether the designed pre-interactive full-body experience was able to mediate the movements of four children aged 8–10 years old to induce either synchronous or nonsynchronous movements, depending on the condition. In contrast to the study conducted by Kirschner and Tomasello (2010) in which the experimenter could influence the interaction between the children, the system is now responsible for mediating the joint task without the need for a human to guide (and interfere in) the experience. The analysis of the pre-interactive Mandala was based on two of the dimensions defined in Rinott and Tractinsky (2022): *Synchronizing Activity (temporality)* and *Triggers and Conditions (object involvement and entrainment stimuli)*.

The first dimension, Synchronizing Activity, focuses on the temporality of the movements at the level of their pattern and precision. The temporal pattern of the movements to catch the glitter cloud was analyzed in terms of whether the children were or were not able to follow the proposed pattern: left-up-right. For this purpose, their movements were categorized according to whether or not they were directed toward the correct circle. The results showed that the most frequently performed movement was the one categorized as Correct. In other words, more than 90% of the time, the movements were directed toward the circle where the glitter cloud appeared. In addition, we found that there was no significant difference between the three conditions in the total percentage of correct movements. This result shows that the visual stimulus, independently of the auditory stimulus, is sufficient and adequate for directing movements toward a specific target in children aged 8–10 years old. Therefore, the visuals of the glitter cloud are sufficient to guide the movement pattern, both in conditions with equal movements in synchronized phase (in a non-mirror spatial configuration) and in conditions with nonsynchronous movements (the same movements performed at different rates).

We have seen that the children's movements followed the proposed pattern well, but the next question to ask is: how precise are these movements? Good synchronization between players also depends on the temporal precision between their movements (Rinott & Tractinsky, 2022). In our pre-interactive experience, the temporal precision between players was analyzed through the accuracy in time between the movements they made to catch the glitter and the instant at which the glitter appeared. Therefore, a good temporal precision with the system in the synchronous movement condition will show a good temporal precision between the movements of the players. We achieved this by categorizing the movements according to whether they were done Before, Similar, or After the glitter appeared inside the circle. The results showed that more than 85% of the time, in all conditions, the movements were performed very close to the occurrence of the glitter cloud. The event categorized as Similar was coded in a window of two seconds (see section 2.4 for more information and for the justification for this time span). Therefore, the maximum difference between the players' movements was two seconds. Furthermore, the results showed that there was no significant difference between the three conditions in the percentage of Similar movements, meaning that the auditory stimulus—that is, the music with a precise rhythm—is not significantly improving the accuracy of the movements when compared to nonrhythmic ambient music. Nevertheless, the results showed very good accuracy outcomes in all conditions, so the visual stimulus appears to be sufficient and adequate, within a two-second window, to direct movements toward the target. It would seem that there is a dominance of the visual stimulus over the auditory stimulus. This is in contrast to what has been shown in other studies, in which they define that a high-precision experience (such as the one presented in this study) tends to require more attention; therefore external stimulation, such as rhythmic music, can facilitate interaction between co-actors (Rinott & Tractinsky, 2022) and emphasize important rhythmic features such as temporal cues (Hoehl et al., 2021). In the pre-interactive experience, the rhythmic music was used as background sound signaling the time of the movement through the beat, accompanied by a melody. As emphasized in Armstrong and Issartel (2014), other types of sound stimuli in addition to visual stimuli should be studied to provide more information on auditory-visual multisensory integration. Also, further analysis should be carried out to study the exact time difference between the catching of the glitter and its appearance, as the present study was performed with a two-second window. According to the previous studies, it could be that the accuracy is tighter in the condition where rhythmic music accompanies the movements.

In addition, the pre-interactive experience encouraged players to move through transitions between the stations after a set number of localized movements. The transition proposed a walking-like movement. The temporal accuracy of the walking movements was analyzed through the temporal accuracy between the instants when the glitter cloud appeared and disappeared, and the start and end of the players' walking. The larger the temporal accuracy with the visual element, the cloud of glitter, the larger the temporal accuracy between the players' march. For this purpose, temporal differences were categorized as Before, Similar, and After movements. The event categorized as Similar was performed in a two-second window. Therefore, the maximum difference between the players' movements was two seconds. At the beginning of the transition, the results showed how the players mostly transitioned at similar times with the system. Moreover, there were also no significant differences in the percentage of similar movements between the three conditions showing, as seen above, that the auditory stimulus did not emphasize synchronization. However, in both conditions with synchronous movements, in approximately 85% of the cases, the movements were performed with Similar accuracy; that is, the time delay between players was no more than two seconds. Additional analyses should be conducted to better understand if the adaptation to the system occurs gradually—in other words, whether movements categorized as After were more likely at the beginning than at the end of the entire pre-interactive experience. Although there are no significant differences between the conditions, in the asynchronous movements condition the percentage of users initiating the transition after two seconds is higher than in the other two conditions. One explanation can be the importance of other players' influence on a player, that is, how we modulate our movements according to the movements of the other people with whom we share the physical space. If no one else is moving, it is more difficult for a given player to understand that she needs to move. Similar results were found at the end of the transition. Players' movements were mostly "similarly" adjusted in all three conditions. In contrast to the beginning of the transition, in some cases, players also anticipated the arrival of the glitter cloud. However, the post hoc analysis showed no significant differences between the different conditions.

The positive results found in temporal pattern and precision show how the pre-interactive experience, the Mandala, is able to foster the movements of the four players facilitating interpersonal entrainment. They also show the importance of studying the integration of visual and auditory stimuli in more detail to learn more about how they can improve IPE.

When designing an interactive experience to promote IPE, it is also important to consider the interactive object used to carry out the interaction with the MR system. It can limit movements to a specific pattern and decrease degrees of free movement which, in turn, can affect synchronous movement (Rinott & Tractinsky, 2022). This brings us to the second target dimension of this study: *Triggers and Conditions (object involvement)*. In the pre-interactive experience presented in this study, the "interactive object" was used to limit the movements to one specific movement: movement performed with the hands and arms back and forth to "touch" (or activate) the glitter cloud. The results showed that more than 80% of the time, the players performed the proposed action. However, significant differences were obtained between two of the conditions: Experimental 1 and Control. The proposed movement was significantly lower in the condition where movements were performed asynchronously (Control) compared to the condition where movements were performed synchronously and with rhythmic music (Experimental 1). As discussed in the results obtained in the transition, the difference may be due to the influence exerted by the players on one another. In the asynchronous condition, the movements were performed at different tempos, which means that the player's movement was not influenced by those of the other players, giving them greater freedom of movement. Interestingly, and considering that the percentages are below 12%, the preferred different type of movement differs between the conditions with ambient music and the condition with rhythmic music. In the conditions with ambient music, the most performed different movement, from the one proposed, was touching the glitter cloud by placing the interactive object on the floor. However, in the condition where the experience was accompanied by rhythmic music, the most performed different movement was jumping into the circle (with two feet). Therefore, the type of music used to support the actions may influence the preference for the type of movement to be performed.

Finally, it was important to analyze the ability of the system to generate good levels of synchrony. The pre-interactive experience mediated the players' movements in the experimental conditions through a visual stimulus (glitter cloud) accompanied or not by an auditory stimulus pacing the entrainment (rhythmic or nonrhythmic ambient music). The results showed that around 50% of the movements were performed with very high levels of synchronicity; that is, 50% of the time the four players were in synchrony between them: moving at the same time with a maximum difference of two seconds. Very high synchrony was followed by High synchrony between the players. The results showed that around 30% of the movements were performed with at least three players in synchrony. Between the Very high and High synchrony levels, players were in synchrony 93.47% of the time in the Experimental 1 condition and 75.68% in the Experimental 2 condition.

The positive results of the "interactive object" show the appropriateness of using it to limit the movement to the desired one. However, further studies should be conducted to understand better the possible interaction between the auditory stimulus and the types of movements to be performed. On the other hand, synchrony among players was mostly between "very high" and "high" levels. These positive results show the system's ability to promote good levels of synchrony between the four players. However, more research should be done to better understand the mechanisms underlying IPE and allow the development of interactive systems that will promote much better levels of synchrony in groups of more than two players.

5 Conclusions and Future Work

In the present study, a pre-interactive experience, the Mandala, has been presented with the aim of fostering the movements of four players between 8 and 10 years old in order to promote good levels of IPE. Literature shows how IPE, in turn, encourages more prosocial behaviors and greater affiliation among co-actors (Cross et al., 2019), the effects which have been shown to persist beyond the lab for at least 24 hours following the entrainment period (Cross et al., 2020). The benefits of IPE strategies can be used to advance social interactions by putting children in a more positive attitude for interacting, and some work even suggests that such movement coordination can reduce negative attitudes amongst polarized groups (Atherton et al., 2019). We have seen that the type of full-body MR system presented allows the use of IPE strategies in a satisfactory way. In addition, by providing a space, players can understand each other's actions and adapt themselves to others (Malinverni & Burguès, 2015). What is more, these full-body MR systems are likely to provide a more immersive, dynamic, and engaging entrainment paradigm than the simpler paradigms often used in this research, which may lead to more prolific social-cognitive consequences.

This study shows preliminary results on the potential of using a full-body MR system to promote IPE through an interactive experience and without the mediation of an external researcher. This allows us to move on to the next phases of the project in which the ability of the MR system to foster IPE when the experience is fully interactive can now be studied. On the other hand, the consequences of the synchronized activity should also be studied through the results obtained in prosociality and group cohesion in stage 3 of the present study (see section 2 for more information). The analysis will shed light on the possible relationships between the elements and actions used to promote IPE and the achievement or not of prosociality and group bonding. In other words, it will allow for a better understanding of the use of full-body interaction systems to enhance positive social interaction through an attitude change, especially for children who have difficulties in performing socially coordinated tasks, such as children with Autism Spectrum Condition (American Psychiatric Association, 2013). Interpersonal entrainment and ASC-based disciplines have begun to be explored together to use interpersonal coordination as a marker of the quality of social interactions and as a mechanism to promote more successful interactions (McNaughton & Redcay, 2020). Therefore, the findings can provide a new approach for the therapists/clinicians working with children with ASC.

The results have provided initial insights into how innovative ICT approaches can change how we think about preventive interventions for people with difficulties in interpersonal communication. This knowledge will allow the community to provide future tools that can be noninvasive, ecologically valid, generalizable, and easy to use by therapists and psychologists.

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