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Short communication

The multimodality of infant's rhythmic movements as a modulator of the interaction with their caregivers

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ABSTRACT

Children's rhythmic movements during the first year of life possess a meaningful predictive validity for later communicative development. However, their role within adult-child interactions is still underexplored. In this study, we examined whether children's rhythmic movements were significantly responded by adults and the role of multimodality and object use in this process. We observed 22 dyads of 9-month-olds and their parents in natural play interactions. Infants' multimodal rhythmic movements increased the probability of adult responding. Adults offered different types of responses and significantly followed the child's focus of attention. These dynamics could support communicative development by promoting joint attention frameworks.

1. Introduction

Rhythmic movements of the arms and hands are a highly characteristic behavior of infants' emerging skills during their first year of life. They are characterized by repetitive and rhythmically-organized body movements that emerge with the child's increased control over their limbs (Iverson et al., 2007). Prior research from an embodiment perspective of infant development, according to which human cognition depends on perceptual and motor capabilities that determine our experiences with others and things (Overton et al., 2007; Varela et al., 1991), has defended that the repetition of rhythmically-organized manual and vocal behaviors may be a transition to the articulated control of the speech-gesture system (Abney et al., 2014; Iverson & Thelen, 1999; Thelen, 1981). This study focuses on how multimodal rhythmic movements (i.e. accompanied by vocalizations and/or gaze towards the adult) produced with objects can give way to the first early communicative gestures. The multimodal rhythmic movements produced by 9 months are related to the first proximal deictic gestures three months later (Murillo et al., 2021). Considering this, our aim is to analyze the adult response to these movements, hypothesizing that this response can foster the socio-pragmatic knowledge needed for intentional communication.

For instance, infants' rhythmic movements have been closely associated with the co-occurring onset of canonical babbling (Ejiri, 1998; Locke et al., 1995), suggesting that first language manifestations result from consistently coupling the vocal and motor systems that get mutually entrained and practiced (Iverson & Fagan, 2004).

During early infancy, the production of rhythmic movements increases with age (Abney et al., 2014; Iverson & Thelen, 1999), while their coordination with vocalizations seems to remain relatively stable across this period (Iverson & Fagan, 2004). First, the rhythmic

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adaptive use of hand and mouth emerges between six and eight months of age, often in mutual coordination. For instance, from a Piagetian perspective, the repetitive movements of the infant would allow them to prolong the interesting effects of their actions on their external environment. From nine months on, rhythmic movements tend to decrease, giving way to coupled but asynchronous gesture and speech utterances (such as reduplicative babbling and rhythmical arm movements that occur with certain time lag between them), and later to synchronous coupling that resemble adult-like gestures and speech (Iverson & Thelen, 1999). In other words, children progressively attain higher degrees of intentional motor control that ultimately contribute to performing and mastering more sophisticated communicative behaviors.

However, while the establishment of strong, specific, and stable links between vocalizations and motor activities has been widely documented (e.g., Abney et al. 2014; Ejiri, 1998; Iverson & Fagan, 2004; Locke et al., 1995; Murillo & Belinchón, 2012), little is known about the role that social interactions exert on it. This is striking because early human communication is largely built upon shared intentionality with others (Murillo & Belinchón, 2012, 2013; Tomasello, 2019) prior to which adults mediate children's first encounters with cultural meanings, and contribute to conveying emotions that turn the interaction into a meaningful whole (Moreno-Núñez et al., 2015). For instance, adults often include objects in their very early interactions with infants, frequently making a rhythmic use of them (e.g., by showing the object or its use to the baby). These rhythmic interactions could act as important resources for infants' socio-communicative development since adults scaffold their participation (e.g., by helping them to complete an action that they are yet unable to fully perform on their own), adjusting the structure of the interchanges to the child's participatory abilities (Moreno-Núñez et al., 2017; Saliba, 2016). When the baby's motor abilities are yet insufficient to hold an object on their own, adults frequently place it in the child's hand and hold it for them (e.g., while interacting with a rattle, they typically place it in the infant's hand and shake his or her arm to make it sound). The direct intervention of adults gradually minimizes as children acquire greater and better abilities to actively participate in the interaction.

Social interactions are core for infants progressive understanding of others and the world, and for them to learn about the consequences of their self-produced rhythmic movements. Infants' rhythmic movements and vocalizations frequently draw attention of others to themselves and their actions, which generates joint intentional activities within a shared conceptual world (Tomasello, 2019). In this scenario, adult responses would lay some common ground in the earliest stages of communicative interchanges, helping to explain potential variations in children's interactional engagement and communicative acquisition (Tamis-LeMonda & Bornstein, 2002; Tamis-LeMonda et al., 2001).

Parental responsiveness refers to prompt, contingent and appropriate responses to the child's vocal and behavioral attempts to communicate, and has been proved to ease the establishment of a range of socioemotional and cognitive outcomes, including language (McGillion et al., 2013; Nelson, 1988; Tamis-LeMonda & Bornstein, 1989, 2002). Its nature follows a dynamic development, in which children's actions often elicit adults' responses which are increasingly congruent with the child's attentional focus (Bornstein et al., 2008; Saliba, 2016). When children are yet unable to intentionally involve adults into their own initiatives, caregivers' responsive and supportive reactions to their behavior are determinant in boosting the interaction, especially if they semantically and temporally match the verbal input to whatever the child is attending to (McGillion et al., 2013). Consequently, infants' communicative gains are expanded when they achieve their communicative goal, which could also foster further uses of the same behaviors (Ger et al., 2018).

This study explores how adults respond to children's rhythmic movements with objects, focusing on the multimodal characteristics (such as concurrent gaze and/or vocalizations) of triadic interactions and how they are synchronized (Murillo et al., 2018). Recent findings suggest that children's multimodal rhythmic movements involving objects at 9 months of age are related to proximal deictic gestures three months later (Murillo et al., 2021). At the same time, adults' contingent responses facilitate the establishment of shared references with children (Tamis-LeMonda et al., 2001) by, for example, decreasing the situational ambiguity (i.e., isolating what to attend to, or what to act upon). Nevertheless, there is limited research documenting how social interactional experiences in the first year of life could serve as a basis for intentional communication. Specifically, our research questions are as follows:

- (a) Are infants' rhythmic movements with objects systematically responded to by adults in an interactive situation?
- (b) Does multimodality (i.e., coordination with gaze and/or vocalization) increase the probability of the rhythmic movement being responded to by the adult?
- (c) When the adults respond to rhythmic movements, do they follow the children's focus of attention?
- (d) What types of response do adults provide to infant rhythmic movements when these movements have certain characteristics (use of objects, coordination with vocalizations and/or gaze)?

Following previous research, we propose that adults' contingent responses to children's rhythmic movements and their emergent communicative initiatives (e.g. gestures) could be a key mediator for early social and emotional attunement.

2. Methods

We observed 22 infants (10 male, 12 female) at 9 months of age ($M = 276$ days, $SD = 8$ days) during a free play situation in a familiar setting (their home or an isolated room at their day-care facility center) with their mother or father, who voluntarily enrolled in the study. The participating families live in middle-class neighborhoods in the Madrid region (Spain). All participants but one (a girl from a Catalan-Spanish environment) came from monolingual Spanish-speaking homes. Children's typical development was ensured through the Spanish version of the Battelle Developmental Screening test (De la Cruz & González, 1996). Twenty-one out of the 22 mothers and 59 % of the fathers had a university degree. Twenty-seven percent of the fathers had secondary education, and three fathers and one mother did not provide information about their academic background. Observations were part of a larger longitudinal

study in which we observed children up to 30 months of age. The study was conducted in accordance with the Declaration of Helsinki and its later amendments, and informed consents were obtained from participating parents.

Adult and child were video-recorded for 12–15 min ($M = 13.05$ min, $SD = 3.07$ min) playing on the floor with the same standard set of toys (blocks, cars, animal figures, eating sets and picture books). Parents were asked to behave in their usual manner. We did not provide instructions about how to use the objects in order to ensure that interactive interchanges remained as spontaneous as possible. The observer placed the video-camera on a tripod at approximately 1.5 m from the participants and did not participate in the interaction unless the child explicitly addressed her.

We coded children behaviors and parental responses from the video-recordings using ELAN (Lausberg & Sloetjes, 2009), a multimedia annotation software that enables high-precision (frame-by-frame) encoding. Based on coding categories from previous studies, (Murillo & Belinchón, 2012; Murillo & Belinchón, 2013; Murillo et al., 2018) we first coded children's behaviors. Rhythmic movements were defined as a motor behavior with the arms or hands that was repeated at least two consecutive times. Further repetitions were considered as part of the same rhythmic movement until the infant returned their arms or hands to a resting position, or they performed a different behavior. Rhythmic movements were coded as *with object* when the child produced them with an object in their hand, or when they banged an object either with their hand or another object. We coded a rhythmic behavior as *without object* when it was performed with no object in the child's hands (i.e., the child shook her hand(s) or arm(s), or banged a surface with her hand(s)). Our coding scheme also included the instances of the infant's gaze towards the adult, and children's vocalizations, which comprised all vocal sounds but excluded vegetative sounds, cries and laughs. Rhythmic movement coordination *with gaze* refers to those instances in which the child directed her gaze towards the adult, either while performing the movement or within a period of 1-s before its onset, or after it concluded. The same criteria applied for rhythmic movement coordination with *children's vocalizations*. We considered a rhythmic movement as multimodal when it was produced accompanied by vocalizations and/or gaze to the adult.

After coding the child's behaviors, we noted whether or not the parent responded within a 3-s window after the child's rhythmic movement. Previous research has shown that a 3-second window is enough time to capture maternal responsiveness (Conway et al., 2018; Kuchirko et al., 2020; Bornstein & Tamis-Lemonda, 1995). When parents responded to more than one behavior in succession, we coded each different behavior of the child and their respective response. When the parent gave two different responses to a single rhythmic movement both responses were separately computed. We analyzed the extent to which adults' responses followed the child's focus of attention, that is, if they referred to what the infant was already attending to or even to his own action or movement (e.g. "Oh, are you moving your hands?"). We also coded the types of response using four groups of mutually exclusive categories of both responsive and directive cues that were adapted from Ger et al. (2018): (a) referential responses such as naming, comments or affirmations, (b) directive responses such as prohibitions or directive utterances, (c) questions, and (d) playing and singing.

Two researchers independently coded the child's behaviors and the parental responsiveness for all participants. Inter-observer agreement based on 13 % of the observations was $k = .73$ for both rhythmic movements and object use, $k = .78$ for vocalizations and $k = .64$ for child's gaze towards the adult. Regarding adults' behaviors, the agreement rate was $k = .77$ for the type of response and $k = .78$ for whether or not they followed the attentional focus of the child.

3. Results

Overall, children produced 406 rhythmic movements. The raw frequencies of rhythmic movements are represented in Table 1. Results showed that adults' responses to children's rhythmic behaviors were very frequent. We conducted a binomial test whose results indicated that rhythmic movements were significantly responded to by the adults ($p < .001$).

For every dyad, we calculated the overall probability that a rhythmic movement was responded to by the adult. We also calculated the probability that a rhythmic movement was responded to by an adult depending on whether the rhythmic movement was produced with an object in the hand, or they were coordinated with vocalizations and/or gaze towards the adult (see Table 2).

We conducted Wilcoxon non-parametric tests to compare the probability of adults' response to rhythmic movements when they were produced with or without an object in the child's hand. The probability of a rhythmic movement obtaining a response from the adult did not increase when children performed it with an object in the hand ($Z = 1.64$, $p = .099$). Then, we compared the probability of obtaining a response when the rhythmic movement was performed with or without vocalizations, and we found that the probability of response did not increase with the vocal accompaniment ($Z = -1.39$; $p = .162$).

Table 1

Frequency of every rhythmic movements produced with and without object, vocalizations and/or gaze and percentage of adult's response to each one of them.

Rhythmic movement	N	With adult's response	Without adult's response
With object	158	129 (81 %)	29 (19 %)
With object + gaze	87	79 (91 %)	8 (9 %)
With object + vocalization	36	33 (91 %)	3 (9 %)
With object + gaze + vocalization	35	35 (100 %)	0 (0 %)
Without object	41	34 (83 %)	7 (17 %)
Without object + gaze	12	12 (100 %)	0 (0 %)
Without object + vocalization	28	24 (86 %)	4 (14 %)
Without object + gaze + vocalization	9	9 (100 %)	0 (0 %)
Total	406	355 (87 %)	51 (13 %)

Table 2

Probability of adult's response to infant rhythmic movements.

	Mean	SD	N
Overall probability of response	.85	.12	22
Rhythmic movement with object	.83	.16	21
Rhythmic movement without object	.89	.16	16
Rhythmic movement with vocalization	.89	.25	19
Rhythmic movement without vocalization	.82	.15	22
Rhythmic movement with gaze	.93	.14	18
Rhythmic movement without gaze	.82	.13	22
Rhythmic movement with vocalization + gaze	1	0	10
Rhythmic movement without vocalization or gaze	.80	.18	22

Regarding the use of gaze, we found that the probability of obtaining a response was higher when the movement was accompanied by gaze towards the adult than when it was not, although these differences did not reach statistical significance ($Z = -1.81$; $p = .069$).

Finally, we compared the probability with which the adults responded to rhythmic movements when they were produced with both gaze and vocalization, to the probability of obtaining a response when the rhythmic movements were produced without any of these accompaniments. We found that the combination of gaze and vocalization when children performed rhythmic movements significantly increased the probability of obtaining a response from the adult ($Z = 2.23$; $p = .026$). However, it should be noted that some children were unable to jointly coordinate these three elements.

Our results also suggest that adults in our sample were prone to follow the children's focus of attention when responding to their rhythmic movements. A binomial test showed that adults significantly responded to children in relation to their rhythmic movement or the object with which it was produced ($p < .0001$). Additionally, adults used a wide range of types of responses for systematically replying to rhythmic movements, accompanying children's communicative attempts with adjusted mediators that promote spaces for their active participation and could foster increasing complexity of their behaviors (Fig. 1). Table 3 shows the mean frequency of every type of adult's response that we identified, where referential cues (i.e. naming, comment and affirmative utterances) were the most frequent, followed by questions, and directive responses and prohibitions. Responses involving play routines or singing were the least frequent.

In order to analyze the effect of the use of objects in the type of adult's response, we conducted a repeated measures ANOVA, taking the frequency of adult's response as the dependent variable. The type of response (referential, question, directive, and play) and the use of object (with object vs. without object) were the factors. We found an interaction effect between the type of adults' response and the children's use of object ($F(3, 63) = 3.84$, $p = .014$, $\eta^2 = .155$, $1-\beta = .79$). Pair-wise comparisons using Bonferroni correction showed that adults posed referential responses more often than play responses when children produced rhythmic movements with objects ($p = .003$), while this was not observed for rhythmic movements performed without an object.

We conducted the same analysis to explore the effect of children's vocalizations on the type of adult's response, where the frequency of response was the dependent variable and the type of response (referential, question, directive and play) and the vocalizations (with vs. without vocalization) were the factors. We found an interaction effect between the type of response and children's vocalizations ($F(3, 63) = 4.24$, $p = .009$, $\eta^2 = .168$, $1-\beta = .84$). More precisely, referential responses were more frequent than play replies in absence of vocalizations ($p = .002$) as shown by pair-wise comparisons using Bonferroni correction. Both questions and referential responses were more frequent after the child performed a rhythmic movement without vocalization than with it ($p = .008$ and $p = .001$, respectively), while play and directive responses were equally produced regardless of the vocal accompaniment of the child's rhythmic movement.

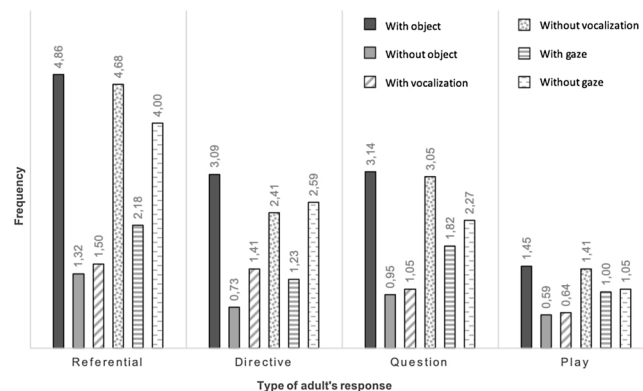


Fig. 1. Mean frequency of adults' response to the infant's rhythmic movements according to their type.

Note. The figure represents the mean frequency of each type of response to rhythmic movements with and without the use of object, vocalization and gaze towards the adult.

Table 3

Frequency of every type of adult's response. Mean and standard deviation.

Type of response	Mean	SD
Referential	6.18	5.09
Directive	3.81	3.44
Question	4.09	3.55
Play	2.04	2.14

Finally, we conducted a repeated measures ANOVA taking the frequency of adult's response as the dependent variable and the type of response (referential, question, directive and play) and the use of gaze (with vs. without gaze) as factors. Results showed an interaction effect between the child's gaze towards the adult and the type of response ($F(3, 63) = 3.05, p = .035, \eta^2 = .12, 1-\beta = .69$). Referential and directive responses were more frequently produced when the rhythmic movement was solely produced than when it was accompanied by a gaze towards the adult ($p = .019$ and $p = .039$, respectively), but this difference was not found either for questions or play responses.

4. Discussion

The adult's response to infant rhythmic movements can have a role on the predictive value of these movements on subsequent gesture use (Murillo et al., 2021), especially when they are multimodal. How adults respond to children's first communicative attempts is core for promoting their development, as they may enhance both children's and adults' ability to share meanings (Vallotton, 2011). While some forms of parental responsiveness have been shown to increase with children age (such as parent's imitations, expansions and play prompts), others tend to remain steady (e.g. exploratory prompts) or decrease, as in the case of adult's affirmations (Bornstein et al., 2008). This fact suggests that certain forms of responsiveness could be appropriate or effective to different extents at different stages of children's development. Moreover, the highly dynamic and complex unfolding of triadic interactions could be fostered by the effect of self-efficiency insights that adults' contingent responses may provoke in children. This is consistent with prior research that shows how adults typically accompany children's behavior while playing with objects by making redundancies and inter-connections, which contributes to establish relevant links between the child's actions and their environment (Suanda et al., 2016). In addition to supporting children's communicative and language development, the results of the present study could lead to important implications for promoting parental responsiveness to infants' early communicative efforts.

From the early stages of intentional communication development, children's rhythmic movements seem to act as a communicative signal for the adult. Our results showed that parents were sensitive to these cues and frequently responded to them, in fact, the co-ordination of vocalization and gaze accompanying the child's actions seems to increase the likelihood of adults responding. For instance, gaze-coordinated vocalizations at the end of the first year have been claimed to be a strong predictor of expressive vocabulary up to 24 months of age (Donnellan et al., 2020). When children accompany their rhythmic movements with vocalizations and gaze it could make their parents perceive their actions more readily as communicative acts, thus being more responsive or accurate when reacting to them. Similar results on parental responses were found by recent studies aimed at analyzing how caregivers react to children's gestures. Adults frequently elaborate through affirmative comments or questions on children's referential intents (Bornstein et al., 2008; Ger et al., 2018), especially if they combined gestures (e.g. pointing) and vocalizations. Conversely, pointing with the whole hand without vocalizations mostly elicited prohibitive responses, which the authors of the studies attribute to caregivers interpreting them as requests to obtain the referents. Furthermore, affirmative and questioning responses at 9 months of age predict children's first words and word combinations later in their development (Tamis-LeMonda et al., 2001, 2014).

While it seems to be still insufficiently researched whether variations in the type of responses that adults provide depend on the referent items, task construal, or language-specific aspects, it has to be noted that recent studies have further explored the culture-specific distinctions of parental responsiveness. Results show that, although parents tend to contingently respond to their infant's communicative attempts across different ethnicities, Latino mothers present higher rates of gestural forms of communication and regulatory language than other ethnical groups in the US (e.g., Kuchirko et al., 2018). However, there is still a need for studies exploring these differences and any potential similarities across families from diverse cultural and ethnical backgrounds.

Our findings suggest that adults' systematic responses to children's rhythmic movements could foster interaction and the establishment of shared references. Our study highlights the generalized use of objects in early interactions, which is why they should be considered as a promising and relevant factor for the study and promotion of early communicative development.

Adults tend to accompany children's communicative development with adjusted, relevant and contingent responses that promote spaces for children's active participation and help to increase the complexity of their behaviors. Referential responses were more frequent than play when there was an object involved in the rhythmic movement, but no differences emerged when an object was not involved. Despite not finding an effect of the presence of vocalizations on the type of adults' response as we would have expected, it is striking that both questions and referential responses were more frequently produced when the rhythmic movement was not accompanied by vocalizations. Adults responded more often to children's rhythmic movements with referential utterances and questions. Previous research has shown that both referential language (especially labelling children's vocalizations) and questions are frequent in child-directed speech later in development (Tamis-LeMonda et al., 2014). Moreover, both strategies promote children's verbal participation in the conversation (see Justice et al. 2018, for a review) and are related to better linguistic skills (Hoff-Ginsberg, 1986). The present study suggests that these forms of responding are already frequent before children produce their first words. The

fact that there were no differences between these forms of response and others in which the child was also vocalizing or using objects during the rhythmic movement, indicates that adults adapt their responses to the child's level of communicative skills (Rowe & Snow, 2020). Namely, parents may not need to respond with referential utterances or questions, which are beneficial to further support children's language, when children already show better communicative skills reflected by their use of vocalization or objects alongside their rhythmic movements.

Despite these interesting results, our study has some limitations that must be considered when interpreting the results. On the one hand, the sample size is limited and is restricted to middle-class families. On the other hand, while the filming situation aims at recreating typical and spontaneous interactions between babies and their caregivers, they are not completely naturalistic since we provided the set of toys. This methodological decision might lead to overestimating the use of objects in true natural situations.

In summary, our results highlight that as multimodality and the use of objects promote shared interactions from the child's focus of attention, they are of paramount importance to communicative exchanges that take place at the end of the first year of life. Parental responsiveness could facilitate the children's transition from rhythmically organized manual and vocal behaviors to the articulated control of the speech-gesture system (Abney et al., 2014; Iverson & Thelen, 1999; Thelen, 1981). Further research analyzing the relationship between rhythmic movements, adult's response and the emergence of the first words is necessary, in order to clarify the role of such movements on early language development.

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Intellectual property

The authors confirm that they have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing the authors confirm that they have followed the regulations of their institutions concerning intellectual property.

Research ethics

This study was reviewed and approved by the Ethics Committee of the Universidad Autónoma de Madrid (ref.: CEI-101-1896). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Authorship

AMN and EM designed the study, EM, MC and IR collected the data. All authors discussed the results and contributed to the final version of the manuscript.

Declaration of Competing Interest

The authors report no declarations of interest.

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