



What's an early triadic interaction made of? A methodological proposal to study the musical dynamics of interaction

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ABSTRACT

Classical theories of intersubjectivity hold that the first interactions in which children participate are dyadic (adult-baby). However, thanks to the material shift that is taking place in the cognitive sciences, an increasing number of authors began to recognise the constitutive role that materiality has for cognition, from the very beginning of life. Interactions do not occur in a vacuum, but within a meaning-loaded material world that adults actively seek to bring to children. While in the field of dyadic interactions studies on communicative musicality have shown how interactive exchanges are structured and how that structure unfolds over time, little is known yet about the internal structure of early triadic interactions. In this paper, we propose a longitudinal, mixed and multilevel methodological framework aimed at describing the dynamics of the musical organisation of early triadic interactions between adults, babies and things, and its development over different timescales. We conclude that if researchers want to fully understand early triadic interactions and their musical structuring, further studies that take into account the cognitive relevance of things and the dynamics of our interactions with and through materiality are needed.

1. Introduction

If a decade ago it was natural for mainstream developmental psychology to think of cognitive processes as skull-bound (i.e., the processing of information within the mind/brain), that is no longer the case. The so-called *4e approaches* (i.e., embodied, embedded, enacted, extended), among other perspectives (e.g., contemporary ecological stances), have extensively demonstrated the potential of understanding cognition as the dynamic interactions between the brain, the body, and the environment (Gallagher, 2017; Newen et al., 2018). From this perspective, the mind is not an abstract dimension, but something we do.¹ Malafouris sums up this idea very well when arguing that:

There is no such universal thing as ‘the mind’, rather there is a variety of human (or by extension non-human) ways of thinking enacted by specific bodies in specific situations (historical, social or cultural). What we call mind is a ‘process’ constituted by the continuous recycling and re-organisation of mind-stuff, i.e., a cognitive becoming (Malafouris, 2019, p. 5).

Certainly, unorthodox paradigms of cognition have meant a shift in our theoretical understanding of such diverse issues as motor skills and their development (e.g., Adolph, 2019; Di Paolo, 2019; Travieso et al., 2020), emotions (e.g., Colombetti, 2007; Vesker et al.,

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¹ It is worth noticing that these contemporary paradigms owe a great deal to the ecological approach, especially to studies recognising the key influence of situated action and the environment on cognition (see, for example, Thelen & Smith, 1994; Thelen et al., 1987).

2020), concepts (e.g., Alessandroni, 2020; Overmann, 2019), memory (e.g., Michaelian & Sant'Anna, 2021), language (e.g., Cuffari et al., 2014; Di Paolo et al., 2018; Gallagher, 2020) and social cognition (e.g., De Jaegher et al., 2010; Gallagher & Allen, 2018; Lindblom, 2020), among others. However, there is still a long way to go in the methodological field. In other terms, there are still many questions about how best to investigate the dynamic interrelationships between brain, body, and the environment in an empirical fashion (see De Jaegher et al., 2017; Heras-Escribano, 2019; Reddy, 2008).

As far as research on cognitive development is concerned, two factors make this methodological challenge even more complicated. First, studying cognition in the earliest stages of development differs from studying adult cognition. One of the reasons for this is that the fast pace at which cognitive processes vary makes it necessary to devise strategies that allow longitudinal variations to be captured with adequate fineness. Second, while psychological studies seem to be increasingly agreeing that material culture is constitutive of cognition—the idea that cognition is something we do *with* and *through* things, within sociomaterial practices (Malafouris, 2018)—, developmental psychology has yet to thoroughly exploit this idea (e.g., Moro, 2016). This material turn could certainly help developmental psychology to advance a much needed *sociomaterial practice-based explanation* of cognitive phenomena (Malafouris, 2020). Thus, it is necessary to design empirical paradigms in which the unit of analysis transcends the classical dyadicity (e.g., adult-baby, baby-object, baby-stimulus) and in which objects are not considered as external stimuli for contemplation or as instruments upon which pre-formed intentions are “poured” (see Alessandroni & Rodríguez, 2020).

As a contribution to our understanding of early social cognition, in this paper, we present a set of methodological strategies to describe the progressive structuring and complexity of the musical components of early triadic interactions (i.e., adult-baby-object interactions). To that end, we embrace an enactive-ecological and cultural perspective for which human development happens through the coordination of behaviour in sociomaterial practices and can be characterised as changes in meaningful interactive systems of dynamic, open, and changing forces (Cox et al. 2019, Hsu & Fogel, 2003, Van Orden et al., 2005, Witherington & Boom, 2019).

In accordance with this, the procedures we describe in this paper allow researchers to (i) detect recurrent temporal and melodic patterns in the actions carried out by children and adults, (ii) to describe the degree of synchrony and the level of interactional complexity taking into account the characteristics of these patterns, and (iii) to identify longitudinal variations. Taken together, these three aspects make up a useful approach to analyse quali-quantitative variations in the interactional structure, thus bringing us closer to a better understanding of how social coordination emerges and what is its role in psychological development.

2. Early interactions: not just dyadic

While many investigations have focused on the origins and development of early communicative acts and social interactions between adults and babies, they typically fall under the assumption that children begin to communicate with others in a triadic fashion only towards the end of the first year of life (Bates et al., 1975; Tomasello, 2004, 2008). In such a perspective, triadic communication is a consequence of a sociocognitive revolution that children undergo at around nine months of age (Tomasello, 2019) that leads to new structured forms of referential communication with others:

Before this age they can engage with objects directly, such as by grasping and manipulating them. They also can engage with other people directly, such as by exchanging emotions with them in protoconversations. But nine-month-old infants for the first time begin to engage with people and objects together triadically—they begin “triangulating” with others on the entities and situations around them (Tomasello, 2019, pp. 55–56).

This theoretical bias determined that considerable effort was put into understanding the structure of early dyadic exchanges, relegating materiality to a secondary place. This is particularly evident in studies on *communicative musicality* (Malloch, 1999; Malloch & Trevarthen, 2009), defined as the neurobiological impulse that drives us to create and share music with others from birth, and that allows us to establish synrhythmic regulations with others (Trevarthen, 2017). According to this approach, early dyadic interactions between adults and children are shaped by musically organised signs that contribute to joint communication and psychological co-regulation (Trevarthen et al., 2006). Importantly, “musicality” is here understood in terms of underlying structure and not in terms of actual phenomena. This would mean that behaviours (e.g., gestures, emotional expressions, etc.) can be a part of the soundscape even if they do not produce an actual sound. Thus, a periodic movement of a leg, for instance, would be deemed “musical” even when it does not produce any sound. Studies on communicative musicality have addressed a variety of topics including the musical characteristics of infant-directed speech (e.g., Fernald, 1989; Keller et al., 2008; Malloch, 1999) and babies’ vocalisations (e.g., Papoušek & Papoušek, 1981), the degree of interactive synchrony between the corporal movements of the mother and the baby (e.g., Condon & Sander, 1974), and the expressive characteristics of adults’ spontaneous singing to the child (e.g., Trehub et al., 1993).

As a result of the emphasis on the dyadic dimension, valuable evidence and exhaustive descriptions of mother-infant interactions and their musical components coexist with a relative lack of knowledge about the relationships between early interpersonal communication and material culture. Contrastingly, a growing body of academic literature has pointed out that interactions never occur in a vacuum, but in specific sociomaterial environments that need to be considered (Costall, 2013; De Schuymer et al., 2011; Fogel, 1993; Striano & Stahl, 2005; Yu & Smith, 2017). In other words, pure dyadicity could not exist because our *cognitive ecologies* (Hutchins, 2010; Ingold, 2013) are constituted by material culture. Of course, as many have noticed, in her first months of life a baby is not yet able to direct the attention of adults to an object she is attending to with the aim of establishing a shared reference (e.g., Tomasello, 2019). However, as we have argued elsewhere, “even when the child cannot blend in the same communicative act one object and another person, he is placed by others in *meaning-loaded material scenarios*” (Alessandroni, Moreno-Núñez, Rodríguez, & Del Olmo, 2020, p. 1556). To put it differently, adults help children to take part in everyday interactions and routines involving objects as

active participants from the very beginning (Kärtner, 2015; Rodríguez & Moro, 2008; Rossmannith & Reddy, 2016). In previous works we have referred to this kind of exchanges that occur from birth as *early triadic interactions* (Alessandroni et al., 2020; Moreno-Núñez, Rodríguez, & Del Olmo, 2015; Moreno-Núñez, Rodríguez, & Del Olmo, 2017) and we have pointed out that these interactions might well be a base for the classically acknowledged triadicity. As a result, we have suggested that it is of utmost importance to analyse the characteristics of adults' actions and children's early engagement. Due to adult scaffolding, children progressively coordinate their actions to that of others and come to engage in more skillful ways with the culturally meaningful action patterns that adults articulate in their action (Kärtner, 2018; Rączaszek-Leonardi, Dębska, & Sochanowicz, 2014). Accordingly, it has been argued that the child is, at the same time, influenced and influential on the world and others. Both adult and child coordinate through dynamic systems of mediation and co-regulation that facilitate the emergence of interactive structures on different timescales (Köster et al., 2016; Nomikou et al., 2016; Rączaszek-Leonardi et al., 2013). If it is true that adults mediate the ways in which children engage with material culture from the beginning of life, then it becomes crucial to unravel the organisation of musical components of early triadic interactions.

As is the case with dyadic musicality, it should be clear that when talking about musicality we are referring to the musical components of interaction and not actual sounds. In the same way that the body can produce rhythmic behaviours, objects can be used "rhythmically" (i.e., following a stable pattern of movements) and following broader and stable temporal organisations (i.e., *tempi*), even if they do not sound at all. Therefore, whether it be producing sound or not, objects should be considered part of the musicality of interactions.

In previous studies we have explored the longitudinal evolution of the rhythmic, sonorous, and melodic components of the uses of objects that adults and children perform in early triadic interactions (Moreno-Núñez et al., 2015, 2017). These components seem to be the basis of an incipient semiotic system that eases interactions around the material world. It also allows adults to segment the world for children and include them into interactions, building shared meanings *with*, *through* and *about* objects. Furthermore, we found that rhythm contributes to the structure and organisation of early triadic interactions.

While our initial studies (Moreno-Núñez et al. 2015, 2017) were focused on describing the communicative mediators that adults typically use within early triadic interactions (such as demonstrations of uses of objects or certain kind of gestures), our latest investigations have started to depict the structural and dynamic characteristics of the interactive musical organisation. In a recent study (Alessandroni et al., 2020), for instance, we analysed video sequences coming from a longitudinal study where a 2-month-old baby interacted with his mother and a maraca at home. The results showed that over the course of the 5 min and 27 s of the interaction, the mother combined musical components and communicative resources in increasingly richer and complex ways. If at the beginning she gave the interaction a rudimentary musical organisation, little by little she elaborated rhythmic patterns, played with tempi variations and pauses, introduced more and more vocal patterns, and included intensity variations. Specifically, we found musical components belonging to three musical dimensions: rhythmic-metric structure (e.g., hierarchical relationships between different metric levels and musical lines, slight or marked musical accents, recurring rhythmic patterns), temporal organisation (e.g., stable temporal organisations and their variations, both sudden and progressive), and other musical parameters (such as organisations of pitches and variations of them in the vocal line, and sketches of synchronisation of musical pauses between different musical lines). Both at the intersegment and intrasequence levels, these musical components formed patterns that were enriched and elaborated, giving rise to differential engagements on the child's side. This suggests that early triadic interactions also follow a musical organisation that spurs the development of communicative skills.

3. Materials and methods

To describe the dynamic variations of the musical components of early triadic interactions over time, we propose that a useful methodological strategy is to conduct descriptive, extensive, multivariate, and longitudinal studies involving non-participant observations in ecological contexts and microgenetic analyses of data. The advantages of such a choice are twofold. On one hand, longitudinal studies of triadic interactions allow researchers to study if there are recurrent patterns of interaction, whether the patterns found at different timescales relate to each other in a systematic way, and how adults (parents and/or educators) promote (and



Fig. 1. Examples of observational settings at home.

discourage), at particular times, specific ways of interacting with objects from the wider spectrum of interactive possibilities. On the other hand, microgenetic analyses can describe with a great level of detail the characteristics of the behaviours by which adults and children communicate when interacting with and through objects. This permits researchers to describe how communicative processes unfold and enrich over time. In the next pages, we depict and discuss the general characteristics of a research method used in a previous pilot study (Alessandroni et al., 2020), and an ongoing R&D project. With this description, we aim at allowing for replication studies and enabling researchers with other interests to design studies from a similar methodological framework.

3.1. Starting conditions and data collection

Using a high-quality video camera, we recorded 10- to 20-minute videos during non-participant observations of children's interactions with an object and an adult (their father/mother or their teacher), either at home (Fig. 1) or at an ECE center. We observed children on a monthly basis during their first year of life, from 2 to 12 months of age.

In previous studies (Moreno-Núñez et al., 2015, 2017), the use of a standardised object proved to be useful in assessing the developmental characteristics of the organisation of musical components of early triadic interactions. Accordingly, in Alessandroni et al. (2020), the object was provided by us. We used a maraca (Table 1), an idiophone instrument formed by a hollow spherical part that is attached to a handle. It is filled with small percussive elements that could range from small-sized stones, natural seeds or rice, to small pieces of other materials such as glass or metal. Although we chose the maraca, it should be noted that other objects could be used as well, provided that they are easy to grasp by children at this stage of development (i.e., their dimensions and weight are manageable for them) (see Table 2 for examples of objects used in previous studies).

Before starting the recording, children were placed by the adult in a comfortable position for interaction. We gave the adults the object and instructed them to play with the child as they would normally do. Because our aim was to leave space for participants to engage through their own strategies, we did not provide instructions about how to use the object, in order to ensure that interactions remained as spontaneous as possible.

3.2. Data analysis

Our proposal was based on a mixed analytical approach (i.e., qualitative and quantitative) that followed a descriptive-comparative schema (see Fig. 2, Table 3).

First, we performed a viewing and a qualitative analysis of the raw video data to identify within each video those interactive exchanges that exhibited musical components (either rhythmic, sonorous, or melodic). Examples of these are the adult's rhythmic use of the maraca, either in a distant (i.e. in front of the baby) or an immediate manner (e.g. placing the maraca in the child's hand and then shaking it to make it sound, or directly "percussing" the maraca against the baby's body, such as the chest, or the tummy). We coded the behaviours of adults and children within second-by-second data frames using ELAN (Prior & van Herwegen, 2016) and the microgenetic procedure described by Rodríguez and Moro (1999). According to this, both adult and child behaviours are transcribed second-by-second in separate lines, allowing for a written understanding on how the interactional sequences unfold. For each participant, data was coded according to two main dimensions, namely (1) attentional processes, vocalisations/verbalisations, and emotional expressiveness; and (2) uses of objects and non-linguistic communicative mediators (e.g., performing a showing or a pointing gesture in relation to the object). In this instance, we used six mutually-exclusive codes for children and five codes for adults (see Table 4) based on previous research carried out from the theoretical approach of the *pragmatics of the object* (Moreno-Núñez et al., 2015, 2017), that were also complemented with emergent categories.² The resulting coding scheme allowed for examining how the musical components were organised within intentional frames of interaction led by the adult, where objects were enacted as complex cultural referents.

Based on this qualitative analysis, we categorised sequences featuring musical components (i.e., those displaying any relationship of regularity, proportionality, recurrency, repetition, or variation among musical characteristics of interaction) as "meaningful". These interactive sequences were extracted with Adobe Premier Pro CC2017 (Version 21), and the audio track for each of them was obtained using Adobe Audition Pro CC2017 (Version 21). One of the researchers, a person knowledgeable in music theory, manually transcribed these interactive sequences using Finale, a music notation software (see Fig. 3, for an example).

We processed the audio tracks in Matlab 2017b (Version 9.3), using 9 mathematical functions of MIRtoolbox (Version 1.7, Lartillot et al., 2008), a computer tool for extracting musical features from audio files. The MIRtoolbox functions that were relevant for our study were *miraudio*, *mirframe*, *mirvelope*, *mirpeaks*, *mirspectrum*, *mirautocor*, *mirtempo*, *mirpulseclarity*, and *mirsimatrix*.³ The utility of each of these functions is detailed in Table 5. For each track and each function, we got continuous scores (intra-frame every 500 ms) and central tendency descriptive statistics (see Fig. 4, for an example of the analysis of a waveform and its tempi variations).

² In our previous study (Alessandroni et al., 2020) we just analysed a single video. However, when videos from different developmental times are available, it is possible to calculate more informative descriptive statistics, intra/interobserver reliability indexes and inter-categorical correlation scores for different behaviours (e.g., uses of the object, gestures), as well as compare distribution variations over time (e.g., through statistical testing or mathematical modelling).

³ It is important to notice that there are open source or free alternatives to the software mentioned in this paper. For instance, MuseScore and NoteFlight can handle musical notation, while the extraction of musical characteristics can be done through Praat or Librosa (a Python package). Audio tracks, in turn, can be obtained with Audacity-like freeware, and Adobe Illustrator could be replaced by open source graphic design suites.

Table 1
Description of the maraca that was used in previous studies (adapted from [Moreno-Núñez et al., 2017](#)).













Object	Object being used	Physical properties
		Height: 12.5 cm. Width: 5 cm. Depth: 5 cm. Weight: 40 g.

Table 2
Other objects used in previous research ([Moreno Núñez, 2014](#); [Moreno-Núñez, Rodríguez, & Miranda-Zapata, 2020](#)).

Object	Object being used
	
	
	
	
	

We decided to focus our quantitative analysis on the comparison of continuous scores and central tendency statistics, both at the intra and intersequence levels.⁴ Through our analysis, we identified and tagged every relationship of regularity, proportionality, recurrency, repetition, or variation among musical characteristics of interaction as an *emergent musical pattern*. Subsequently, we analysed and compared the degree of musical organisation of the interactive sequences by looking for the reiteration of musical components of interaction, the reiteration of the organisational structure of musical components of interaction (e.g., patterns), and the dynamic variation of musical organisation throughout the different interactive sequences. To do that, we specifically looked at the following parameters: (i) relationships between metric levels, (ii) musical accents, (iii) stable metric organisations, (iv) recurrent rhythmic patterns, (v) silences, (vi) stable tempi organisations, (vii) isochrony relationships, (viii) pitch organisations, (ix) the synchronisation of musical pauses between different components, and (x) the alternation of phonetic particles.

For each parameter, we first defined, based on the researchers' musical knowledge, a "minimum" and a "maximum" degree of

⁴ When analysing multiple videos, researchers can export the data to other environments (e.g., RStudio) to perform more complex analyses, such as a comparison of individual cross-recurrence quantification analyses (see [Dale et al., 2011](#); [Wallot & Leonardi, 2018](#)) pertaining to different developmental times.

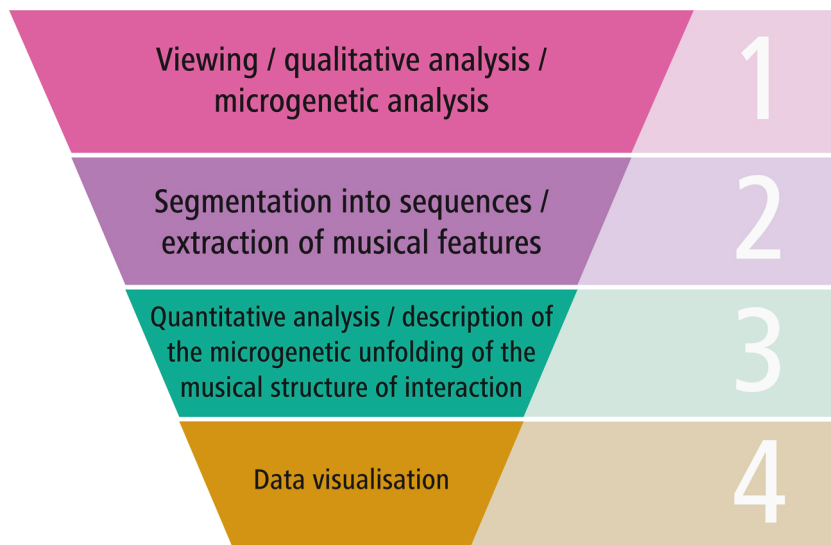


Fig. 2. Methodological steps of our proposal.

Table 3
Steps of the data analysis process.

Step	Research goals	Software	Outputs
Viewing, qualitative analysis, and microgenetic analysis	To identify interactive exchanges that exhibit musical components	ELAN	Meaningful video sequences featuring musical components
Segmentation into sequences and extraction of musical features	To obtain numerical data about the musical components of interactions	Adobe Suite CC MATLAB (MIRtoolbox) Finale	Continuous scores (intra-frame every 500 ms) and central tendency descriptive statistics for each function / transcriptions of interactions using musical notation
Quantitative analysis / description of the microgenetic unfolding of the musical structure of interaction	To describe the dynamic variations of the musical organisation over different timescales	MATLAB	Comparison of continuous scores and central tendency statistics, both at the intra and intersequence level / definition of degrees of musical organisation of triadic interactions
Data visualisation	To show the variations of the musical structuring of early triadic interactions in an easy-to-grasp format	Adobe Suite CC	Simplification and dissemination of findings

Table 4
Observation categories.

Children	Adults
<p><i>Uses of objects</i></p> <p>Non-canonical uses: Uses of objects according to what they physically allow and not according to its cultural function (e.g., sucking the maraca).</p> <p>Proto-canonical uses: Uses more directed than the non-canonical ones. They announce the appearance of canonical uses (e.g., attempting to grasp the maraca; shaking the maraca in an elemental way).</p> <p>Canonical uses: Uses of objects according to their cultural-defined function (e.g., shaking the maraca).</p> <p><i>Ostensive gestures</i></p> <p>Ostensive gesture: Gestures –with no movement– involving an object to draw the attention of the child (e.g., showing or giving the maraca).</p> <p>Rhythmic-ostensive gesture: Ostensive gestures that exhibit rhythmic and sonorous characteristics as a reiteration (e.g., isochronous organizations of movements).</p> <p><i>Vocalizations</i></p> <p>Vocal sounds produced by the child.</p>	<p><i>Rhythmic-sonorous demonstrations</i></p> <p>Performances of conventional rhythmic-sonorous uses of the object directed toward the child (e.g., shaking the maraca).</p> <p>Distant: Demonstrations of use made from a distance (e.g., playing the maraca).</p> <p>Immediate: Demonstrations of use introduced through (joint) actions involving the child's body (e.g., playing the maraca on the child's body; putting the maraca on the child's hand and moving it).</p> <p><i>Ostensive gestures</i></p> <p>Ostensive gesture: Gestures –with no movement– involving an object to draw the attention of the child (e.g., showing or giving the maraca).</p> <p>Rhythmic-ostensive gesture: Ostensive gestures that exhibit rhythmic and sonorous characteristics as a reiteration (e.g., isochronous organizations of movements).</p> <p><i>Language, vocalizations, and psalmody</i></p> <p>Words and vocal sounds produced by the adult, both with the articulation style of the spoken voice and of psalmody (i.e., with a monotonous tone).</p>

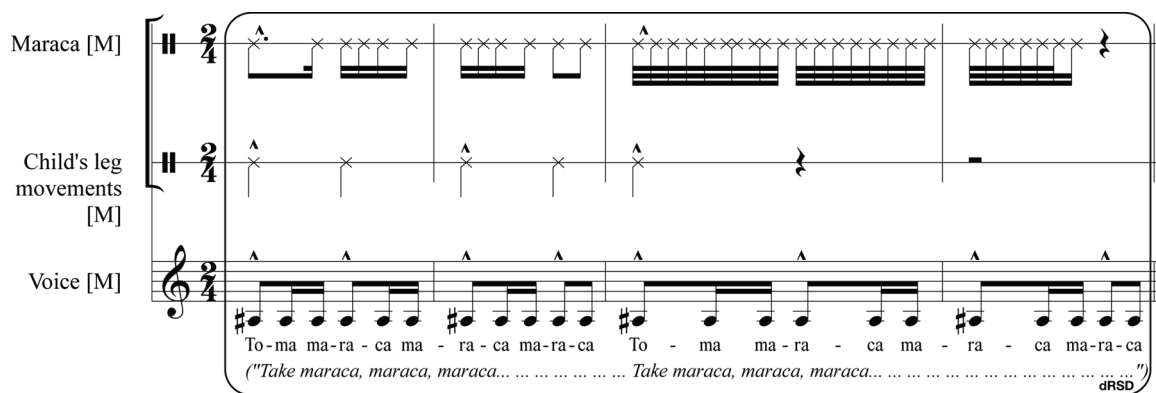


Fig. 3. Example of an interactive sequence transcribed to music notation using Finale. Reprinted by permission from Springer: Alessandroni et al. (2020).

musical organisation. It is worth noting that the words "minimum" and "maximum" have a meaning relative to our videos and not an absolute definition. That is to say, for example, that "maximum" does not denote a maximum degree of "universal" musical organisation (which would be, on the other hand, impossible to consider) but the maximum degree of musical organisation found among our sequences. Next, for each sequence and parameter, we assigned a score ranging from 1 to 5, where 1 was the "minimum" degree of musical organisation, and 5 was the "maximum" one. Finally, we calculated each sequence's overall complexity taking into account the partial scores corresponding to each parameter.⁵

The combination of this information allowed us, finally, to understand the microgenetic unfolding of the musical structure along the triadic interaction under study and to describe precisely which musical elements were added, removed or varied within and between interactive sequences (see Fig. 5, for a heatmap chart portraying the variations in complexity).

4. Conclusions

Material culture is a constitutive part of our cognitive ecologies: things are not passive referents of our thought, but that *with which* and *through which* our cognitive becoming takes place. Whenever we use objects, we usually do it in rhythmic and/or sonorous ways. In that respect, musicality is one of the dimensions of analysis of thought processes that happen with/through things. According to this, we hold that if researchers want to understand early interactions and communicative musicality in all its complexity, further studies that take into account the cognitive and interactive relevance of things are needed. The methodological approach we proposed here is one way to achieve this goal, since it aims at describing in great detail the dynamics of the musical organisation of early interactions between adults, babies and things.

The innovative character of our proposal comes from a number of reasons worth considering: (1) it addresses the description of musicality in early triadic interactions that are commonly forgotten in other investigations; (2) it adopts a novel pragmatic, functional and situated approach that transcends the limitations of perception-based approaches (i.e., only describing musical components without paying attention to the actions performed by the children and the mother/father/educator); (3) it features a longitudinal, ecological and qualitative/quantitative methodology that surpasses the limitations of experimental research (see Alessandroni & Rodríguez, 2020); (4) it combines the analytical power of different software; (5) it is based on sociocultural theories of development that consider communication and semiotic mediation as constitutive of human cognition; and (6) it considers objects as constitutive of interactions and thinking processes.

It should be noted that our methodological perspective was mainly aimed at extending the analysis of musical characteristics to the field of early triadic interactions. In other words, we defended the idea that beyond dyadic interactions, unraveling the dynamics of triadic engagements with objects provides a great deal of information on early communicative musicality and its development, and therefore should be taken into account. In no way, however, can the described methodology answer, on its own, how the musical organisation of early triadic interactions differs from the one found in dyadic interactions. To answer this most interesting question researchers could, nonetheless, undertake a comparative research approach, whether it be descriptive or explanatory. As for other limitations, it should be noticed that due to the age of the child whose interactions we analysed, we focused primarily on the mother's actions. Also, as the object (a maraca) was provided by us, we could not assess how diverse objects actively shape, in differential ways, the musical characteristics of interactions. It would also be possible to add a phenomenological layer to the analysis by viewing and

⁵ It would be certainly possible to compute a more precise, standardised *complexity index* (not based on the researchers' musical judgment) by establishing time frames and calculating the variations in each parameter's numeric values throughout each video sequence. However, due to our research project's aims, we decided to use the numerical information as one more input to judge, subjectively, the degree of musical organisation in each case. Importantly, even if automating the calculation of complexity could provide a more accurate measurement, it could also result in neglecting qualitative features of the interactions.

Table 5
Description of MIRtoolbox functions to be used in the study (Lartillot et al., 2008).

MIRtoolbox function	Description of its effect
<i>miraudio</i>	Loading, transforming, displaying, and performing operations on the audio waveform of an input audio file
<i>mirframe</i>	Creating short-term windows that move chronologically along the temporal signal in order to take into account the dynamic evolution of musical features
<i>mirenvelope</i>	Computing the envelope of an audio waveform, showing the global outer shape of the signal
<i>mirpeaks</i>	Detecting peaks or important local maxima of an input audio file
<i>mirspectrum</i>	Decomposing a signal along frequencies using a Fast Fourier Transform to highlight the repartition of the amplitude of the frequencies
<i>mirautocor</i>	Evaluating periodicities in signals by looking at local correlation between samples
<i>mirtempo</i>	Estimating the tempo of an input by detecting periodicities from the event detection curve
<i>mirpulseclarity</i>	Estimating the rhythmic clarity, indicating the strength of the beats estimated by <i>mirtempo</i> function
<i>mirsimatrix</i>	Computing the similarity matrix resulting from the mutual comparison between each possible frame analysis of an input

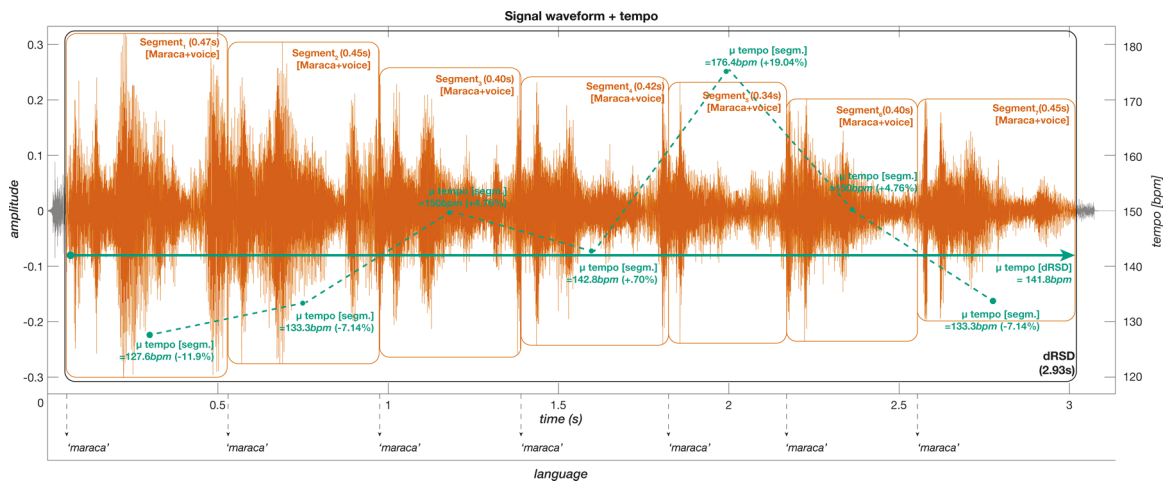


Fig. 4. Signal waveform of an interactive sequence with segmentations according to adult's actions and tempi variation analysis. Reprinted by permission from Springer: Alessandroni et al. (2020).

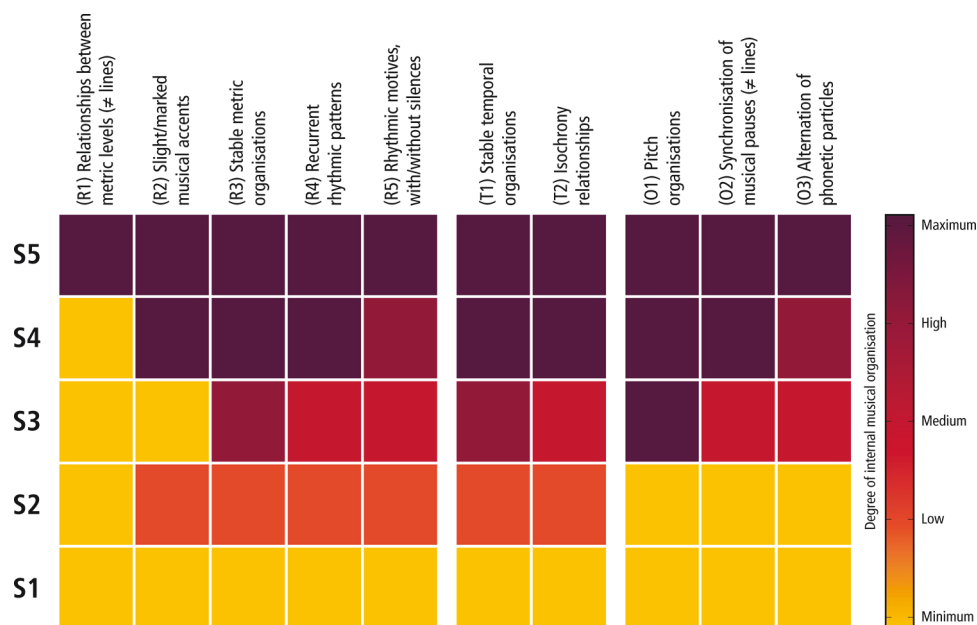


Fig. 5. Heatmap chart representing the degree of S1–S5 internal musical organization. Reprinted by permission from Springer: Alessandroni et al. (2020).

discussing the videos jointly with the participating adults. For instance, researchers could ask adults about the meaning of their actions or the intentions they had while interacting. This would allow researchers to gain additional information from the participants, for a fully situated perspective on how they and their cultural selves get enacted in everyday environments (Kimmel, 2008). Further studies could address these issues.

Beyond these limitations, we believe that if researchers were to carry out more studies from the perspective we describe in this paper, they could produce results relevant for psychological theory and policy-making in ECE, particularly with regards to the development of interactions and social interactions in early childhood. They may also contribute to a better understanding of social/communicative development, improving parenting practices (especially those related to parent-child communication), and enhancing educational processes in ECE by considering the musical features of human interactions.

Authors' statement

The authors declare that they contributed to this manuscript by the following activities:

AMN: Conceptualization; Data collection & curation; Funding acquisition; Writing - original draft, review & editing.

NA: Conceptualization; Methodology; Software; Data visualization; Writing - original draft, review & editing.

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