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Understanding rhythmic behavior in infancy: Perspectives for addressing developmental, methodological, and analytical challenges

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ABSTRACT

Neural sensitivity to rhythm emerges prenatally, yet observable movement synchronization to an external beat occurs later and more gradually over development. Integrating findings from developmental psychology, neuroscience, music cognition, and social interaction research, we propose a triadic framework suggesting that infants' rhythmic synchronization emerges from the interaction of three components: rhythm perception, motor development, and social scaffolding. Based on this framework, early synchronization abilities may be present earlier than commonly assumed, but their expression depends on interactions between perceptual capacities, developing motor abilities and social scaffolding, providing predictive cues and reward. We further argue that the detection of early rhythmic behavior may depend on methodological and analytical approaches as infant rhythmic behavior is variable, context-dependent, and expressed intermittently. Methodological and analytical improvements are outlined to better capture the dynamic development of rhythmic coordination in infancy. Understanding variability in early rhythmic behavior will provide insight into developmental trajectories and be informative for identifying early markers of potential deficits in rhythm processing, which have been described in neurodevelopmental disorders.

Introduction

Rhythmic patterns in music and language facilitate segmentation, prediction, learning and memory (e.g., Fiveash & Tillmann, 2024; Goswami, 2011; Large & Jones, 1999; Trainor & Corrigall, 2010), and in social contexts, coordinated rhythmic movements enhance bonding and cooperative behaviors (e.g., Cirelli et al., 2014, 2016, 2018; Trainor & Cirelli, 2015). Perceptual sensitivity to rhythm emerges prenatally (Edalati et al., 2023), but the development of synchronized rhythmic movement has been reported to appear later and more gradually (Nguyen et al., 2025; Rocha, Southgate, et al., 2021). Here, we propose that infants' behavioral

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rhythmic synchronization abilities might be present earlier than previous studies suggest, with their expression depending on perceptual, motor and social constraints as well as on the sensitivity of testing methodologies and analyses.

We here present an integrated triadic framework (Fig. 1) proposing that infants' development of synchronized rhythmic behavior (i.e., behavioral expression of rhythmic synchronization abilities) emerges from the interaction of three components: (i) perceptual entrainment, (ii) motor production capacities and (iii) social scaffolding. The first three sections review each of these components, notably that infants detect temporal regularities from early age, even prenatally (perceptual entrainment); developing motor abilities allow rhythmic synchronization to emerge in production, and social scaffolding (in particular via familiar caregivers) provides predictive cues, reward, and reinforcement that guide the emergence of behavioral synchronization and its observability. The novelty of the framework is not in identifying these components separately, which has been done in previous research, but in proposing their joint consideration for potentially revealing observable synchronization earlier in life. We propose that these components interact and mutually inform each other. For example, perceptual processes inform motor adjustments, which are refined through social feedback; and social reward strengthens timing and coordination over repeated interactions. Aiming to explain the mismatch between early neural entrainment in perception and intermittent or absent behavioral synchronization, we discuss the influence of testing context and implementation and then highlight the importance of sensitive methodology and analyses approaches. Infants' early synchronization abilities might be underestimated when motor demands are high, social scaffolding is weak, or analyses rely on group/trial averages. Taken together, this leads to the hypothesis that synchronization might emerge on the basis of perceptual timing abilities, motor readiness, and social reward, and might become observable with more sensitive methodological and analytical measures. The triadic framework thus proposes a lens for integrating perceptual, production-related, and social influences on emergence and expression of rhythmic abilities in infancy, and outlines how methodological, analytical, and contextual factors shape the way these behaviors can be detected in infancy.

The triadic framework

Rhythm perception

A first requirement for rhythmic synchronization is the ability to perceive and extract temporal regularities, such as the beat (the regular pulse in a sequence of sounds) and meter, which organizes beats into hierarchical cycles of strong and weak accents (e.g., Cannon & Patel, 2021; Large et al., 2023; McAuley, 2010; Thaut et al., 2014). Early theoretical accounts suggested that the temporal and rhythmic organization of language materials, such as infant-directed speech and lullabies, plays a central role in shaping early perceptual capacities (Trehub et al., 1993; Trehub & Trainor, 1990). For example, behavioral work showed that newborns discriminate between languages based on rhythmic class (Nazzi et al., 1998; Ramus et al., 2000). EEG studies showed infants' sensitivity to hierarchical rhythmic structures when listening to music-like materials. Newborns' neural responses differ between event omissions at metrically strong versus weak beats (Bianco et al., 2025; Háden et al., 2024; Winkler et al., 2009), and between 7 and 15 months of age, their neural activity show peaks at both beat and metrical frequencies (Cirelli et al., 2016).

Younger infants entrain to nested beat groupings, with 6-month-olds exhibiting top-down meter activation when primed to duple or triple patterns (Flaten et al., 2022; Lenc et al., 2023). Even preterm infants, as young as 32 weeks gestational age, show neural peaks at

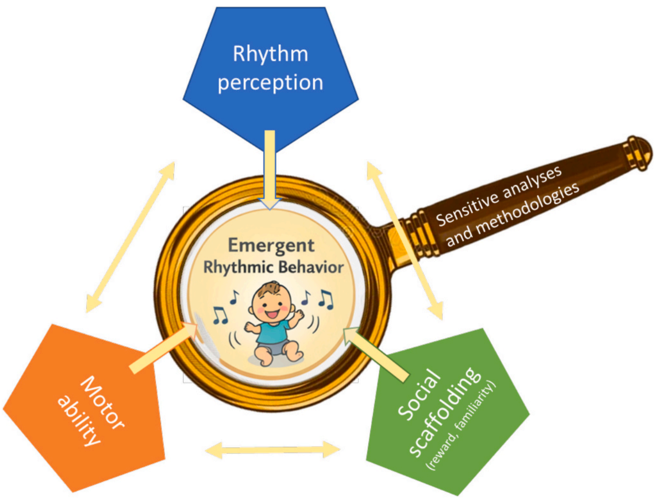

Fig. 1. The figure illustrates the triadic framework proposed here, which positions *emergent rhythmic behavior* at the center, depicted as observable rhythmic actions synchronized to music in infancy. Three interacting domains surround this core: rhythm perception (perceptual processing of temporal structure), motor ability (production capacities enabling rhythmic movement), and social scaffolding (including reward, familiarity, and caregiver interaction). The lens indicates methodological and analytical factors (e.g., testing situation, recording techniques, individual- and trial-based analyses), whose sensitivity further influences how we can capture the dynamic development of rhythmic coordination in infancy.

beat and meter frequencies (Edalati et al., 2023), with phase-alignment to the auditory envelope. Across preterm infants aged 27–35 weeks, synchronization to the beat frequency is present at all ages, whereas slower metrical groupings appear only in the older preterms (Saadatmehr et al., 2024). Neural synchronization has been shown for instrumental music and nursery rhymes in 8-month -old infants (Cantiani et al., 2022) and for live maternal infant-directed singing in 7-month-old (Nguyen, Flaten, Trainor and Novembre, 2023a). For sung and spoken nursery rhymes and naturalistic speech materials, amplitude envelope fluctuations, stress patterns, and hierarchical temporal regularities contribute to the extraction of rhythmic information (Attaheri et al., 2022; Di Liberto et al., 2023; Menn et al., 2022), revealing infants' sensitivity to a diverse range of rhythmic cues embedded in ecologically communicative signals.

This early perceptual entrainment capacity, captured by the first element of the triadic framework, provides predictive timing information that can guide motor behavior and social coordination. As infants' immature motor skills develop, perception-action coupling strengthens, allowing infants to translate perceived temporal structures into coordinated movements and stable behavioral alignment to emerge.

Developing motor system and rhythm production

The second component of the framework concerns the development of the motor system and the ability to produce rhythmic movements. In contrast to the early perceptual sensitivity to rhythmic structures, the ability to synchronize movements to an external beat develops more gradually and becomes more precise only later in childhood (Nguyen et al., 2025; Rocha et al., 2021; see Hannon et al., 2018 for a review). Neural evidence showed that motor regions are already engaged during rhythm perception in late preterm infants (Rajabi et al., 2025), suggesting that auditory-motor coupling mechanisms may be functionally present before overt synchronization is behaviorally observable. In 3- to 5-months old infants, synchronization appears minimal or absent, and movements, including rudimentary limb actions and vocalizations, look largely spontaneous rather than aligned with an external beat (i.e., phase-locked), although phase-locking may occur in a subset of infants (Fujii et al., 2014). Around 5 months of age, infants exhibit spontaneous motor tempo in drumming tasks, reflected in sequences of hits with consistent onset timing and hand coordination, though stable phase-locking to external rhythmic stimuli is still developing (Rocha, et al., 2020, 2021). Between 6 and 10 months of age, infants show preferred tempi, displaying more regular and sustained movements at intermediate (e.g., inter-onset intervals, IOIs at 500 ms) than faster rates, even though their movements are not phase-locked with external stimuli (De l'Etoile et al., 2020). By approximately 9 months, repetitive rhythmic movements tend to peak in co-occurrence with canonical babbling (Ejiri, 1998; Ejiri & Masataka, 2001), suggesting early links between motor rhythms and emerging language skills. Toddlers and preschoolers show increasing coordination and flexibility in rhythmic production. Around 2 years of age, toddlers' drumming entrains to isochronous tone sequences presented audio-visually at different tempi (IOIs between 400 and 700 ms), with stronger synchronization observed in social than nonsocial contexts (Rocha & Addyman, 2022). By 3 to 4 years of age, children reliably adjust tapping in both social and nonsocial drumming tasks to faster and slower tempi (IOIs of 400 and 600 ms), suggesting growing integration of perceptual input with motor planning and execution (Kirschner & Tomasello, 2009; Yu et al., 2022; Yu & Myowa, 2021). From early school age onward, children gradually approach adult-like synchronization abilities. Between 5 and 8 years of age, they show increasingly regular tapping, improved tempo flexibility, and reduced IOI variability, with musical training enhancing performance (Carrillo et al., 2024; Ireland et al., 2018; Monier & Droit-Volet, 2019; Nave et al., 2023; Nave-Blodgett et al., 2021; Thompson et al., 2015). Adults reliably coordinate movements with external rhythms, adapt to tempo changes, and maintain an internal representation of the beat even in the absence of an external pacing stimulus (Bouwer et al., 2021; Repp, 2005; Repp & Su, 2013; Von Schnehen et al., 2022), showing mature rhythmic perception, beat extraction, motor production and sensorimotor coordination.

This developmental pattern suggests that the gap between perception and production reflects immature motor development (Adolph & Franchak, 2024; WHO, 2006), rather than the absence of rhythmic competence. The triadic framework proposes that motor development acts as a production constraint that limits the behavioral expression of perceptually available timing information. As infants' motor control improves, they gradually acquire the capacity to translate internally represented temporal structures and timing predictions into coordinated rhythmic movement (see also Schwarzer & Jovanovic, 2024).

Importantly, even the precursors of rhythmic coordination might be underestimated or difficult to detect without considering the interaction of perceptual and social factors, in addition to the motor factors. The expression of rhythmic behavior in infancy may be further influenced by how synchronization is elicited, with which material and in which situation. The nature of the auditory material may play a critical role: Simple isochronous sequences (e.g., metronomes) provide explicit temporal cues, whereas musical stimuli require beat extraction but are more engaging (e.g., Cameron et al., 2023) and rewarding (Fiveash et al., 2023), potentially facilitating beat synchronization (i., e., alignment with the beat). Additional powerful sources of motivational value are social contexts and interactions with caregivers or social partners, which provide affective feedback and reinforcement that can enhance infants' engagement and support stronger synchronization than in nonsocial settings. From this perspective, beat synchronization emerges through a dynamic interplay between infants' developing perceptual and motor capacities and the environment in which they are embedded, with both stimulus-driven and socially-mediated rewards shaping how and when rhythmic coordination is expressed.

Social context and expression of infants' rhythmic capacities

The third component of the framework is social scaffolding. Theoretical accounts increasingly emphasize that cognitive capacities, including executive functions and language, best emerge through interaction rather than in isolation (Bosseler et al., 2024; Endevelt-Shapira et al., 2024; Frick, 2025; Kuhl, 2011). Similarly, rhythmic synchronization is a socially embedded behavior that develops through coordinated movement interaction with others (Hoehl et al., 2025). Not only does social context shape rhythmic engagement, but rhythmic synchronization itself feeds back into and strengthens social affiliation. Early synchronous experiences promote prosocial behavior (Cirelli et al., 2014; Tunçgenç & Cohen, 2018), and synchronized rhythmic movements between infants and adults increase helping behaviors and affiliative preferences, even without music (Cirelli et al., 2017). Joint musical engagement also enhances prosocial behavior in preschool-aged children (Kirschner & Tomasello, 2010; Wan & Zhu, 2021).

Collectively, these findings suggest that early rhythmic movement is best understood as a socially embedded behavior, arising from and contributing to joint attention, mutual engagement, and cooperative interaction. In experimental settings testing rhythmic behavior, variations in social/non-social context, might differentially support the expression of synchronization abilities. For example, 2- to 4-year-old children show improved synchronization when drumming with another person compared to solo conditions (Kirschner & Tomasello, 2009; Yu et al., 2022; Yu & Myowa, 2021). Partner identity may also play a role, potentially depending on age: While 10- to 18-month-old infants showed no social partner effect when drumming with an experimenter (in comparison to a nonsocial condition in which infants drummed while watching a visual animation; Rocha & Mareschal, 2017), older infants, aged 18 to 30 months, synchronized more reliably when the social drumming condition was implemented with a caregiver rather than with a robot (Yu & Myowa, 2021), suggesting that familiarity and social reward can modulate rhythmic engagement (see also Nguyen, Flaten, Trainor and Novembre, 2023a using live maternal infant-directed singing).

Synchronizing with others appears to be intrinsically rewarding, and this reward value can strengthen predictive timing and interpersonal alignment over repeated interactions (Fiveash et al., 2023). Converging evidence from animal research underscores the role of reward: The "four components" (4Cs) framework proposes that successful synchronization requires (i) an auditory component from which to extract temporal patterns, (ii) a predictive component to anticipate future events, (iii) an auditory-motor component to time motor actions, and (iv) coordination of these elements through intrinsic or conditioned reward (Rajendran et al., 2024). For human infants, caregiver smiles, contingent responses, and vocal encouragement may function as social rewards that reinforce emerging timing and coordination skills. The InCHORRRuS framework (Alviar et al., 2025) suggests that caregivers naturally structure their signals to be repetitive, redundant, and rhythmically regular, thereby engaging infants' perceptual biases and creating predictable temporal patterns (Lense et al., 2022). Such rhythmic structuring may scaffold early dyadic coordination and communication (see also Nguyen, et al., 2023b), providing a social context in which infants' emerging synchronization capacities can be expressed and gradually refined.

Environmental testing contexts may further modulate the expression of early rhythmic synchronized behaviors by modulating infants' social responsiveness and access to rewarding social interactions. Although research directly comparing infants' rhythmic behaviors across laboratory and home contexts is currently lacking, studies have documented infants' spontaneous rhythmic behaviors in naturalistic home environments, providing insight into how these behaviors unfold in familiar, everyday contexts. For the first year of life, home-based observations illustrate how spontaneous rhythmic movements develop (Cirelli & Kragness, 2025; Cirelli & Trehub, 2019; Kragness et al., 2022), and parent-based questionnaires have tracked changes in infants' rhythmic responses, highlighting the role of household musical routines in shaping infants' early rhythmic engagement (Kathios et al., 2024; Kim & Schachner, 2023; Politimou et al., 2018). Hammack et al. (2023) showed that in-home data collection enables the analysis of natural parent-infant synchrony, revealing that spontaneous rhythmicity is tightly linked to social coordination and affective attunement. Infants' social responsiveness seems to vary across contexts, with home environments often promoting more sustained attention and contingent interaction than laboratory settings (Tang et al., 2023). Although laboratory settings allow controlling environmental factors and isolating variables to establish causal links, home environments provide rich, socially familiar contexts that may meaningfully influence the expression of infants' rhythmic engagement.

Social scaffolding might thus provide motivation, reward, attentional support, contingent feedback, and structured interaction that together support the emergence and expression of rhythmic behavior and beat-based synchronization (Alviar et al., 2025; Fiveash et al., 2023). Socially engaging contexts may initially enhance movement, attention, and motivate repetition, thereby facilitating temporal processing and increasing opportunities for rhythmic coordination development. Over repeated interactions, contingent feedback, shared attention, and reward may reinforce alignment with external rhythms. Together, the perceptual, motor, and social components interact dynamically, and rhythmic behavior becomes observable when these components align within a supportive context.

The triadic framework also implies that whether early rhythmic abilities are detected depends strongly on how behavior is measured. If rhythmic behavior is variable, context-dependent, and expressed intermittently, then methodological and analytical approaches become critical. We therefore turn to methodological and analytical challenges in the next section.

Challenges and methodological innovations

Methodological and analytic choices likely influence whether and what kind of rhythmic abilities can be observed in infancy. Rhythmic behavior is often analyzed by averaging across individuals, across trials, and also across the entire duration of each trial, with the goal of reducing noise, increasing statistical power, and identifying generalizable group-level effects. While this approach is well suited for detecting stable, population-level patterns, it may obscure meaningful aspects of early rhythmic behavior, which is likely highly heterogeneous or intermittent. Some infants may show strong periodicity or phase alignment for extended periods, while other infants may show such behaviors only on certain trials or on part of a trial, and still others may show intermittent or context-specific rhythmic engagement. Across-participant and across-trial averages can bias inferences toward "false negative" conclusions, particularly during developmental moments when rhythmic behaviors may still be rare. For example, if a specific rhythmic behavior emerges at 3 months, but occurs only in some trials, averaging across trials and participants could make it appear below chance-level, unless extremely large samples are used. Further, the frequency and stability of these behaviors are themselves informative, providing indicators of developmental maturity that can be tracked longitudinally to reveal the emergence and refinement of rhythmic capacities.

Empirical examples illustrate these concerns. In a social drumming condition, individual circular statistical analyses revealed that some participants (about 2- to 4-years old) reached significant levels of synchrony, but when these data were averaged across the group, such effects were diluted (Kirschner & Tomasello, 2009). Similarly, when analyzing the data of the 3- to 5-month-old infants individually, limb movements were aligned with the musical beat for a subset of infants, reaching significant phase-locking (Fujii et al., 2014). These findings suggest that group-level analyses may hide meaningful rhythmic entrainment present even in young infants, underscoring the importance of analytic approaches that capture individual variability in early rhythmic synchronized behavior. Moreover, synchronization may vary not only across individuals and trials, but also *within* a single trial. Infants and toddlers may initially engage in turn-taking, play-like interactions with a caregiver or experimenter, resulting in anti-phase tapping, and later shift toward in-phase synchronization as the interaction unfolds. Similar dynamics have been reported in adult-infant interactions in behavioral and brain synchrony studies (Egmose et al., 2017; Wilcox et al., 2025a). When analyzing average behavior across the entire trial, these distinct but internally consistent coordination modes, anti-phase and in-phase, cancel each other out. These considerations recommend more sensitive analyses of infants' rhythmic abilities, including individual-level circular statistics, analyses of rhythmic bouts rather than whole trials, and time-resolved approaches (e.g., sliding-window analyses) to capture emerging synchronization dynamics. Hierarchical models may further help separate infant-, trial-, and context-level variance while modeling individual and trial variability rather than treating it as noise.

In addition to these analytic choices, methodological choices need to be considered, notably whether movements are captured through isolated limb actions (e.g., hand drumming) or full-body tracking. For example, tapping tasks that measure hand movements (e.g., Kirschner & Tomasello, 2009; Yu et al., 2022; Yu & Myowa, 2021) are informative, but capture only one narrow aspect of infants' rhythmic capacities. Whole-body motion capture or video coding studies can reveal that infants spontaneously produce rhythmic, dance-like movements involving the head, arms, torso, and legs (Eerola et al., 2006; Fujii et al., 2014; Zentner & Eerola, 2010), suggesting that infants' rhythm processing can be expressed across the whole body or across body parts (e.g., swaying followed by tapping). Recent advances in markerless motion tracking, full-body kinematics, high-resolution video, and in-home recordings have enabled the detailed analysis of infants' body movements, even when spontaneous and socially situated (for a review, see Wilcox et al., 2025b). These methods have been applied in dyadic interactions to capture infant-caregiver behavioral synchrony in the home environment, providing sensitive measures of interactive aspects, such as infant engagement and coordination during social interactions (Hammack et al., 2023). They have also been used to assess general movement production in early infancy (Marchi et al., 2019) and to demonstrate the feasibility of fully digital approaches for measuring rhythmic entrainment from within the participant's home, even in very early developmental stages (e.g., Rocha & Addyman, 2022).

All-day naturalistic recording tools like LENA (Gilkerson & Richards, 2008; Oller et al., 2010) provide fine-grained temporal measures of caregiver–infant interaction, including turn-taking and vocal production (Laudańska et al., 2025), which are linked to neural and cognitive development (Romeo et al., 2018; Weisleder & Fernald, 2013; Zimmerman et al., 2009). Wearable motion sensors allow longitudinal tracking of infant-adult movement synchronization in home settings (see Wilcox et al., 2025a; Wilcox et al., 2025b); and when combined with audio recordings, they will provide a multimodal, longitudinal view of rhythmic coordination across contexts and activities. These technologies would allow capturing infants' behavior in more natural situations that benefit from the social scaffolding discussed above and thus provide situations favorable to reveal infants' abilities. Parent-report tools, such as the Music@Home questionnaire (Politimou et al., 2018), can further complement these measures by capturing music-related environmental influences on infants' rhythmic experience. Home measurements extended to music become further relevant for our understanding of individual differences in light of recent reports suggesting that musical activities, in particular infant-directed singing, could enhance caregiver–infant interactions, with rhythm playing a central role (Alviar et al., 2025; see also Smith & Kong, 2025). Combined with analytical choices that examine individual behavior, trial-level dynamics, and time-varying measures, these various methodological approaches may reveal early rhythmic abilities that were previously difficult to detect. This thus proposes not only to refine measurements, but to increase the visibility of the very phenomena under study. Infants, at a very young age, may indeed produce rhythm across the whole body, dynamically adjusting to social partners and selectively responding to auditory stimuli that are socially engaging and rewarding, such as a familiar song sung by a caregiver in infant-directed style. Thus, methodological and analytical sensitivity acts as a lens through which rhythmic behavior becomes visible. The triadic framework therefore not only proposes how rhythmic synchronization emerges, but also why it might have been underestimated in early infancy up to now.

Conclusions

We propose that synchronization capacities in infancy emerge through a dynamic interplay of perception, motor development, and social scaffolding. As shown by neural entrainment in EEG studies, rhythm and beat perception emerge early. While early motor behavior may show rhythmic or periodic structure, which might reflect spontaneous timing and developing motor abilities, it is not necessarily stable or aligned with external auditory rhythms. Beat-based sensorimotor synchronization in young infants seems highly context-dependent, emerging only under specific social and methodological conditions, in subsets of infants. Our framework further highlights that the apparent gap between early perceptual sensitivity to rhythm and later observable synchronization abilities may reflect not only developmental constraints, but also limitations in measurement sensitivity of the experimental implementations and the analyses approaches.

The triadic framework has implications for understanding developmental variability, including in pathology. Understanding variability in early rhythmic behavior is relevant because rhythmic timing abilities are linked to broader cognitive and motor processes (e.g., predicting language development, (Nguyen et al., 2023b; Ní Choisdealbha et al., 2023), and are known to be impaired in several neurodevelopmental conditions (e.g., Fiveash et al., 2021; Ladányi et al., 2020; Lense et al., 2021). Studying individual differences and developmental trajectories in infants' rhythmic behavior may therefore provide early insight into developmental pathways and reveal potential risk markers for cascade effects later on. The framework motivates improved measurement conditions for capturing these abilities and their development. Longitudinal work can investigate how early rhythmic abilities relate to later developmental outcomes and guide defining potential clinical markers of atypical development. Different components of rhythmic behavior (Fiveash et al., 2020) may carry distinct developmental relevance, including perceptual entrainment, motor behavior (period- and phase-matching), and within-individual/trial variability in rhythmic coordination.

Finally, adult research showed the critical role of social partners in shaping rhythmic coordination, with distinct neural signals for social coordination that go beyond the sum of self- and partner-generated movements, emerging only when partners can see each other (Bigand et al., 2025). Future research needs to investigate whether similar mechanisms may be present for infants' synchronization, in particular in familiar social situations and with familiar partners (whether caregivers or peers). The rewarding nature of socially engaging musical activities in a familiar home environment together with familiar songs, and clearly structured rhythmic cues (e.g., the beat played by a drum embedded in the music) may provide supportive contexts for eliciting early synchronization. Methodological advances, such as marker-less full-body motion tracking and in-home recordings, together with data analyses at individual, trial, and dynamic levels over time provide further promising tools to reveal infants' rhythmic abilities and their development.

The triadic framework generates several predictions for the investigation of rhythmic abilities and their development: Behavioral synchronization should emerge earlier in socially engaging and rewarding contexts, especially with familiar caregivers and rhythmically structured music in naturalistic testing environments (vs. in the laboratory), and sensitive analyses of within-individual and trial-level dynamics may detect coordination earlier than group-averaged approaches. Studying individual differences and developmental trajectories (e.g., in longitudinal studies) are expected to reveal how perceptual entrainment, motor coordination, and social responsiveness progressively interact across development. In sum, the development of rhythmic synchronization in infancy should be understood as a gradual process and as a perceptual-motor-social phenomenon whose expression depends on developmental capacities, social environment, and measurement approach. By integrating these factors, the triadic framework provides a conceptual and methodological foundation for future research aimed at identifying the developmental origins of rhythmic synchronization and understanding its emergence and its variability across early development.

CRediT authorship contribution statement

C. Iorio: Writing – original draft, Writing – review & editing, Visualization, Supervision, Conceptualization. **R. Román-Caballero:** Writing – review & editing, Conceptualization. **L. Trainor:** Writing – review & editing, Conceptualization. **S. Moghimi:** Writing – review & editing, Resources, Project administration, Funding acquisition, Conceptualization. **B. Tillmann:** Writing – original draft, Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

No data was used for the research described in the article.

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