



Investigating the Impact of a Music Training Programme on the Development of Rhythm, Lexicon, and Executive Functions in 2- and 4-Year-Olds

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Abstract

Many studies have explored the relationship between music and developmental skills, suggesting that musical training may foster rhythm, lexicon, and executive functions. However, the existing literature has mainly focused on preschoolers, considering a single developmental domain or long-term programmes. This study implemented an 8-week music training for 2- and 4-year-olds with a sample including 54 toddlers ($M_{\text{age}} = 29.0$ months) and 54 preschoolers ($M_{\text{age}} = 52.9$ months), divided into experimental (62) and control (46) groups. A pre-post training design was employed, considering rhythm (using the Rhythmic Imitation test, Stamback, 1980), lexicon (using the Picture Naming Game, Bello et al., 2010 and the Peabody Picture Vocabulary Test, Stella et al., 2000), and executive functions (using Circle Drawing, Fish, Stroop Day/Night, Keep Track, Usai et al. 2017a). Repeated-measures ANCOVAs with parental education as covariate showed a significant training effect on rhythmic skills both for toddlers and preschoolers, with the latter showing a greater increase in rhythmic skill than the former. An effect was also found on executive functions in preschoolers, but not on lexicon at the two ages. Finally, a correlational analysis showed a partial relation between rhythm and lexical comprehension, inhibitory control speed, and working memory accuracy in the older sample. Music training emerges as a sensitive approach to support early skills of 2 and 4-year-olds in nursery and kindergarten, promoting continuity and integration in educational programming.

Keywords 2-4-year-olds · Musical training · Rhythm · Lexicon · Executive functions

Introduction

Music and Rhythmic Development in Early Childhood

Music is a core element in all human cultures, being a universal dimension across all populations (Brown & Jordania, 2013; Ding et al., 2017; Kotz et al., 2018). It is not merely a cultural artefact; it is also strictly related to different developmental domains. One of the main aspects of music is rhythmic organisation; this is particularly important in children between 0 and 6 years old, as it is related to other

developmental competencies, such as language and executive functions (Frischen et al., 2019; Patel, 2008; Tierney & Kraus, 2013).

Musical rhythm can be described as an ordered sequence of tones with varying durations that unfolds within a temporal structure defined by a repeating pattern of beats, known as the metre (Frischen et al., 2022; Schulkind, 1999). Metre provides an organisational framework by grouping beats into recurring cycles characterised by alternating strong and weak accents. Within this framework, the beat, or tactus, represents a single unit of the metrical structure and corresponds to the tempo at which listeners most naturally synchronise movements such as tapping or clapping (Large et al., 2015; London, 2004; Tichko et al., 2022). When the tempo of a rhythmic sequence is altered (by accelerating or slowing it down), the proportional relationships among the individual beats remain unchanged. Tempo refers to the overall speed of the music, that is, the rate at which beats

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occur over time (Frischen et al., 2022; McAuley, 2010). In this study, rhythm (specifically, rhythm reproduction) is the variable considered.

From a perceptual perspective, rhythm discrimination is initially universal in infancy, allowing sensitivity to native and non-native rhythmic patterns. By the end of the first year, perceptual narrowing occurs, with infants showing tuning to the rhythmic structures of their cultural environment (Hannon et al., 2012; Hannon & Trehub, 2005a, b; Soley & Hannon, 2010).

Neural responses to rhythm also reflect experience-dependent plasticity across multiple time scales and can be shaped by embodied interactions such as being rocked in synchrony with music (Phillips-Silver & Trainor, 2005). Finally, rhythm plays a central role both in musical learning and as a developmental facilitator for broader learning processes (Dalcroze, 2008; Miendlarzewska & Trost, 2014).

On the social level, rhythmic coordination supports early caregiver-infant interactions, fostering joint attention, emotional regulation, and motor alignment (Cirelli et al., 2016; Phillips-Silver & Trainor, 2005; Tichko et al., 2022). Rhythm is, therefore, a key feature of musical intervention and a cross-domain mechanism that has a beneficial impact on development in other domains, particularly language and executive functions (Miendlarzewska & Trost, 2014; Tierney & Kraus, 2013). As a transversal competence, rhythm contributes to multiple developmental domains, including temporal prediction, attentional regulation, auditory working memory, movement and cognitive control, mechanisms involved in language acquisition, and executive functioning, even in early infancy (Frischen et al., 2019; Patel, 2008; Tierney & Kraus, 2013).

As a result of the central role of rhythmic ability for development, several researchers and professionals have in recent years implemented music/rhythmic training programmes in educational services specifically designed for children aged three to six (e.g., Vinales del Egado, 2023). These interventions often draw on the Orff-Schulwerk approach (Piazza, 1979, 1983) or adopt other methodologies that prioritise musical exploration, movement, and rhythm-based activities (Habibi et al., 2013).

The Relationship Between Music and Verbal Language in Early Childhood

Music and language share deep perceptual, neural, and social connections that support core aspects of early communicative development, including lexical acquisition (Patel, 2008).

From a perceptual perspective, both domains rely on the ability to analyse and temporally organise complex auditory signals: music is characterised by a hierarchical

structure of rhythms, accents, and melodic patterns, whereas language input contains prosodic cues used by children to segment speech and identify early words and syntactic structures (Brandt et al., 2012; Gordon et al., 2015; Magne et al., 2005). This strong correspondence is also illustrated by Patel and Daniele (2003), who found that languages with more regular prosody are associated with musical traditions featuring pronounced rhythms. In contrast, those with more variable prosody tend to align with musical styles marked by weaker metric accentuation. This perceptual convergence is supported by developmental skills in the early years: more advanced musical abilities are linked with enhanced language competencies, particularly those related to lexical development, such as phonemic awareness, vocabulary growth, and early word recognition in children aged 4 to 6 years (Anvari et al., 2002; Corrigan & Trainor, 2011; Ho et al., 2003). These findings suggest the presence of shared low-level auditory processing mechanisms across both domains.

At the neural level, musical experience has been associated with increased plasticity in brain regions involved in language processing, such as the superior temporal gyrus, planum temporale, and inferior frontal areas (Schneider et al., 2002; Zuk et al., 2014). Music training has also been shown to enhance speech processing in noisy environments in children aged 3 to 4.9 years, indicating functional overlap in neural circuits responsible for fine-grained auditory perception (Thompson et al., 2016). In addition, genetic and neuroscientific research has reported shared biological foundations between music and language, suggesting that innate predispositions may support their parallel development (Fedorenko et al., 2009; Nayak et al., 2022).

Socially and culturally, music also serves as a powerful vehicle for transmitting and reinforcing linguistic structures. For instance, infant-directed singing, toddlers' rhymes, and lullabies create multisensory and relational experiences that are fundamental for communicative development in early childhood, with implications for children's lexical acquisition (Papadimitriou et al., 2021). Such activities, typically embedded within family interactions, support lexical development and emotional regulation through direct and reciprocal exchanges between caregivers and children (Williams et al., 2015).

The Relationship Between Music and Executive Functions in Early Childhood

Music also plays a significant role in developing Executive Functions (EFs), a set of higher-order cognitive abilities encompassing inhibitory control, working memory, and cognitive flexibility (Diamond, 2013). Musical engagement involves the simultaneous coordination of rhythmic,

melodic, and temporal components, thereby drawing on selective attention, planning, and updating short-term memory (Münste et al., 2002). Among young children, inhibitory control appears to be the EF component most closely associated with musical experience, consistent with its earlier development (Bugos & DeMarie, 2017). This is because, according to Diamond (2006), EFs do not all develop simultaneously; rather, they emerge at different ages. In particular, inhibitory control appears to be the first executive function to develop, as it is the one most closely linked with sensorimotor skills, a fundamental and primary element in 2-year-old children, and associated with musical sensorimotor integration. While evidence for working memory and cognitive flexibility is robust in school-aged children (Bergman Nutley et al., 2014; Diamond, 2006; Kausel et al., 2020), findings in younger cohorts remain limited and inconsistent, with authors who are uncertain about their developmental trajectories in toddlers and preschoolers (Degè & Frischen, 2022).

At the neural level, EF-related networks, such as the dorsolateral prefrontal cortex and cortico-subcortical connections, are also recruited during music processing, indicating a shared reliance on neural resources that support both temporal coordination and behavioural regulation (Münste et al., 2002). Furthermore, musical experiences situated in social and interactive contexts may amplify cognitive benefits for two- to five-year-old children: shared activities such as singing or engaging in regular musical routines promote cooperation, turn-taking, and self-regulation skills essential for the development of executive functions (Hughes & Devine, 2019; Williams et al., 2015). Notably, early exposure to music within the family setting, particularly between the ages of two and three, has been linked with improved attention, emotional regulation, and prosocial behaviour in preschool-aged children (Williams et al., 2015).

The Impact of Early Music Interventions on Language and Executive Functions

Studies on music-based training in educational settings (e.g., Lu et al., 2025; Pino et al., 2023) differ according to the developmental domain considered (language, executive functions), and the type of control implemented (active—for example, another type of intervention—or passive, like a no-intervention condition).

Within the language domain, Bolduc et al. (2020) demonstrated that a 19-week music-and-movement programme improved phonological processes in five-year-olds compared with a no-intervention control group. Complementary evidence comes from studies employing active or alternative training conditions: Vidal et al. (2020) found that a 30-week music programme led to

greater phonological awareness than an art-based alternative in three-year-olds. Vinales del Egado (2023) reported that rhythm-focused training, delivered over 18 weeks, was more effective than intonation-based activities in enhancing phonemic awareness in preschoolers. And Newland (2013) showed that supplementing instruction with additional music over 18 weeks produced stronger gains in phonological awareness among five- to six-year-olds than with a standard daily lessons control group. Although all these studies consistently demonstrate the positive impact of music-rhythmic training on phonological abilities, they largely overlook another crucial aspect of early language acquisition: lexical development. To our knowledge, few previous studies (e.g., Pino et al., 2023) have systematically evaluated the effect of music-based interventions on the development of vocabulary or lexical processing skills in toddlers and preschoolers. It represents a significant gap in the literature, considering the central role of lexical acquisition in early language development. It is important to fill this gap because early word comprehension is based on the child's language input segmentation through rhythmic and prosodic indices, which are particularly salient in early child-directed language (Gervain, 2018; Jusczyk, 1999) and can also be found in music elements. Thus, the prosodic and rhythmic aspects of a language lay the foundations for language comprehension and, subsequently, production. Early lexicon growth relies on the contribution of basic perceptual and attentional abilities, which support speech processing, as well as on more complex conceptual mechanisms that allow children to abstract word meanings from the immediate context and to understand words as non-referential linguistic symbols (Bloom, 2000; Waxman & Lidz, 2006).

Regarding executive functions, Shen et al. (2019) demonstrated that a 12-week music programme (five 45-minute sessions per week) enhanced inhibitory control, working memory, and cognitive flexibility in four-year-olds compared with a no-intervention control group. Similar benefits were observed in studies employing active control conditions: Bowmer et al. (2018) compared a 16-week programme (40 min per session) across music, art, and no-intervention groups, reporting potential gains in inhibitory control among three- to four-year-olds, while Bugos and DeMarie (2017) found that six weeks of twice-weekly, 45-minute music instruction outperformed Lego-based activities in fostering inhibitory skills, although no effect emerged for tasks requiring inhibition of a dominant verbal response.

Other programmes further support these findings. Degè et al. (2022) found that, among five- to six-year-olds, 14 weeks of daily 20-minute training led to greater improvements in

inhibitory control in the music condition than with phonological and physical training; and Moreno et al. (2011) reported more significant cognitive improvements and changes in brain activity in four- to six-year-olds following 20 days of one-hour music instruction than with visual arts training.

Similar effects were found in music-movement-based interventions. Suppalarkbunlue et al. (2022) observed superior inhibitory control in four- to five-year-olds after an eight-week music-and-movement programme (three 45-minute sessions per week) compared with storytelling and free play. Bayanova et al. (2022) reported that, in four-and-a-half- to six-year-olds, supplementing general music and dance activities with additional bi-weekly lessons for at least one month led to greater improvements in inhibitory control, audio-verbal working memory, cognitive flexibility, and overall executive function coordination than with a control condition in which children continued with standard music and dance activities. All these studies have consistently shown that music training enhances inhibitory control, but, to our knowledge, few contributions (e.g., Lu et al., 2025) have systematically evaluated the effect of music-based interventions on the development of working memory in preschoolers. The lack of quantitative and systematic studies on this executive function requires investigation, given the strong emergence of this competence between four and five years of age (Diamond, 2006). In particular, filling this research gap is important because music, especially its rhythmic component, supports the implementation of basic selective attention, planning, and updating of working memory (Münste et al., 2002), all of which are fundamental elements in the development of EFs.

Despite the valuable contributions of the studies discussed, all music interventions remain restricted to the three-to-six age range. To our knowledge, there is a notable lack of quantitative research that explicitly targets typically developing children aged zero to three. Again, most of the cited contributions looked at long-term music programmes or a single developmental domain. While the interventions mentioned above served as a source of inspiration for the design of this training programme, the objective of the present study, by contrast, was to develop an integrated short-term music curriculum, with a strong rhythmic component, that would encompass both nursery and kindergarten settings and which would produce significant effects on lexicon and EFs.

For these reasons, designing a music training with a strong rhythmic component could support two key emerging skills, such as lexicon and EFs. Furthermore, it could be a practically relevant response to a critical gap in early childhood education research and practice.

The Present Study

The overall aim of the present study is to evaluate the impact on rhythmic abilities, lexical skills, and executive functions of an eight-week music training programme for two- and four-year-old children. According to the reviewed literature, we expect the effects of the music training to differ according to age and developmental domain. The specific aims are as follows:

1. (a) To assess the intervention's validity in developing rhythmic skills. We expect to find improvements in children's rhythmic competence because, by combining listening, movement, musical production, and rhythmic reading, it is possible to enhance the link between motor and auditory brain areas, and so enhance the capacity to perceive, maintain, and reproduce a rhythmic pattern (Phillips-Silver & Trainor, 2005; Tichko et al., 2022). Moreover, this music training programme comprised activities related to rhythmic sequences that were repeated over time, and exercises focused on musical reading competence. (b) Second, to examine age-related differences in the musical training effects on rhythmic competence. Toddlers and preschoolers exhibit qualitatively different rhythmic skills. For example, around the age of two, children begin to display sustained rhythmic movements and demonstrate flexible, reasonably accurate coordination with auditory rhythms (e.g., Drake et al., 2000; Provasi & Bobin-Bègue, 2003) or exhibit drumming ability with a partner in interactive contexts (e.g., Endedijk et al., 2015; Kirschner & Tomasello, 2009), enabling them to maintain a simple, regular rhythm (Yu et al., 2022). By contrast, at approximately four years of age, children are generally capable of following and reproducing more complex rhythmic patterns (Rizonico & Oddi, 2021).
2. To assess the effect of the music training on lexical development. While previously cited interventions have mainly focused on phonological awareness, few have considered lexical development. Given that rhythmic and prosodic indices are fundamental for the child's language input auditory segmentation, which supports vocabulary comprehension and production (Tierney & Kraus, 2013), we expect a potential effect on lexicon in both age groups, especially in the younger cohort, because they are in the more sensitive period for lexical comprehension and production (Kuhl, 2004, 2010).
3. To assess the effect of the music training on executive functions. Given the multisensory, embodied, and interactive nature of early musical experiences, we hypothesise that music training may support the development of executive functions, particularly inhibitory

control and working memory, which are frequently targeted by music-based interventions (Bolduc et al., 2020; Bowmer et al., 2018; Shen et al., 2019; Vidal et al., 2020). We anticipate that the most substantial improvements will emerge in preschool-aged children, whose cognitive maturation is at a developmental stage that supports the emergence and consolidation of executive functions (Best & Miller, 2010; Garon et al., 2008; Usai et al., 2017a, b). In contrast, we do not expect to observe measurable effects in toddlers, given that, during the first three years of life, the components of executive functioning are still in their early formative stages and not yet clearly differentiated or reliably measurable (Garon et al., 2008).

4. To assess the relationship between rhythm, lexicon, and executive functions. As reported in the literature, rhythmic skills are a basic competence in early childhood that can support lexicon (Brandt et al., 2012; Magne et al., 2005) and executive functions (Miendlarzewska & Trost, 2014). In toddlers, rhythm can be crucial in the emergence of lexical ability, because its perception is initially universal and shaped by early embodied and social experiences such as synchronous movement and caregiver-infant interaction (Hannon & Trehub, 2005a, b; Phillips-Silver & Trainor, 2005; Tichko et al., 2022). In preschoolers, rhythm could be related to executive functions, such as inhibitory control and working memory, which are more developed at this age (Bergman Nutley et al., 2014; Best & Miller, 2010; Diamond, 2006; Garon et al., 2008; Kausel et al., 2020; Usai et al., 2017a, b), while in toddlers, by contrast, inhibitory control is still emerging (Diamond, 2006) and working memory is not yet fully established (Diamond, 2006; Garon et al., 2008).

Method

Participants

Participants were selected from eight educational services (four nurseries and four kindergartens) in a city in the north of Italy. Written informed consent was obtained from 118 families before testing. Children who did not complete at least one assessment in both test phases were excluded from the analysis. The final sample consisted of 108 subjects.

The children were semi-randomly (keeping them in their regular classes) divided into two conditions, each composed of 2- and 4-year-olds: (i) a training group (TG) that completed the music intervention in the first phase and (ii) a waitlist control group (WCG) that participated in the music training only in a second phase. In the meantime, the latter

group continued the regular educational activities in the respective classes. The children's and their parents' demographic details at pre-training are reported in Table 1.

The Ethics Committee of the University of Verona approved the study protocol (ethical approval code: 2023_35).

Procedure

The research started in October 2024, with a first meeting with educators, teachers, and families. Informed consent forms and a socio-demographic questionnaire were given to the parents. It took two months to obtain the completed sheets. In November 2024, four researchers conducted the pre-training assessment (T1) of the children's competencies in rhythm, lexicon, and executive functions. In January 2025, the training group started the 8-week music sessions. In March and April 2025, all children (training and waitlist control groups) were tested again on the same skills (T2, post-training assessment). After that, from April to May 2025, the waitlist control group participated in music training to guarantee, for ethical reasons, the inclusion of all children; however, it was not tested again on rhythmic, lexical, and executive functions.

To avoid confounding variables related to the practice, professionals were asked not to repeat the musical activities proposed during the project period. Furthermore, the professionals were asked to avoid other music-related activities as much as possible throughout the entire project.

Measures

Multiple instruments were used to assess the competencies of the toddlers and preschoolers in a range of developmental domains: rhythm, lexicon, and executive functions.

Table 1 Demographic and background characteristics of the sample grouped by toddlers and preschoolers

Characteristic	Toddlers	Preschoolers
Training condition	31	31
Waitlist control condition	23	23
Female (n)	33	25
Bilingual children (n)	12	24
Age at pre-training (months), <i>M</i> (<i>SD</i>)	29.0 (2.90)	52.9 (3.58)
ISEE (€), <i>M</i> (range)	15,000– 20,000 (10,000– 30,000)	10,000– 15,000 (10,000– 30,000)
Maternal education (years), <i>M</i> (<i>SD</i>)	16.3 (3.28)	14.6 (4.39)
Paternal education (years), <i>M</i> (<i>SD</i>)	15.2 (3.05)	13.8 (4.51)

The ISEE (Indicatore della Situazione Economica Equivalente) is the Italian means-testing indicator that combines household income, assets, and family composition to assess eligibility for social benefits and subsidies

Rhythm

Rhythmic ability was assessed using the Rhythmic Imitation (Stamback, 1980) test. Since this is a standardised test for school-age children rather than 2- and 4-year-olds, a simplified version was administered, which focuses only on reproducing rhythmic structures (and not on spontaneous beat or the understanding and reproduction of the symbolism of rhythmic structures). Despite its partial application, this tool was chosen for two reasons: it is based on the imitation of short rhythmic sequences, a paradigm widely used in developmental research to assess early rhythmic abilities, and it provides a clear list of rhythms to be reproduced. Given the absence, to our knowledge, of standardised rhythmic reproduction tests for children between 2 and 4 years of age, the task was not administered for normative purposes but used as an experimental measure of emerging rhythmic reproduction abilities.

To ensure developmental appropriateness, the task was simplified and adapted according to age group. In both the nursery and kindergarten samples, rhythmic patterns were presented through hand tapping accompanied by vocal sounds (“tam” to emphasise the presence of a beat to be reproduced and “sh” to highlight the pause) to enhance perceptual salience and support imitation. For the nursery group, visual access to the examiner’s gesture was allowed, and no barriers were introduced. In contrast, the kindergarten cohort was presented with rhythmic sequences only in the auditory modality, thereby preventing visual imitation. These adaptations were introduced to reduce cognitive and attentional demands while preserving the core structure of the rhythmic imitation task.

To complete the test, the children listen to short rhythmic sequences performed by the adult, tapping, and are asked to reproduce them by imitating the rhythm. If the children are able to reproduce the rhythm proposed by the examiner, the test continues with increasingly complex sequences. The administration is stopped after four consecutive unsuccessful rhythmic structures in two attempts each, but continues until at least structure 12 (out of 21). The score is obtained by summing the number of correctly imitated sequences, one point for each successfully reproduced structure.

Lexicon

The toddlers’ lexical ability was assessed using the Picture Naming Game (PinG; Bello et al., 2010). The children (19–37 months) engage in symbolic play with an adult and are prompted to understand and name objects, adjectives, or verbs. Accordingly with the recommendations, the children were first given the subtests relating to nouns and then those relating to predicates. Both comprehension and production

of nouns and predicates were assessed simultaneously, alternating between the target stimuli. The score corresponds to the number of words that are correctly understood and produced (one for each correct answer). In the comprehension subtest, the examiner identifies and codes only the correct responses, i.e., those in which the children point to, touch, or pick up the photograph corresponding to the target stimulus named by the examiner. For the production subtest, responses in which the children correctly name the photograph are coded as correct. Additionally, onomatopoeia, simplified correct responses, synonyms, and dialectal forms consistent with the target are also acceptable.

The preschoolers’ lexical abilities were assessed using the Peabody Picture Vocabulary Test (PPVT; Stella et al., 2000). This test can be administered from the age of two to adulthood. The subjects listen to a word and select the corresponding image from four options, and the administration begins with the identification of the baseline, i.e., the basic level of vocabulary, and the ceiling, i.e., the maximum limit beyond which the subjects are unlikely to understand further vocabulary. To identify the baseline, the children must answer eight consecutive vocabulary items correctly; while the ceiling is set by six incorrect answers in eight consecutive attempts. The final score is calculated by subtracting the number of errors from the baseline-ceiling range.

Executive Functions

The toddlers’ motor and inhibitory control were assessed using the Circle Drawing (Usai et al. 2017a) task, which is suitable for children aged between 2 and 6 years. The subjects are told a story about a child and his turtle friend, as they both walk along the road, represented by a printed circle placed in front of the children. The story is depicted by two pawns (one for the child and one for the turtle) that carry out the action. Once the children have been shown how to do this, the examiner asks if they want to move the human token on the circle and measures how long it takes to complete the task. Next, the examiner asks them to do the same with the turtle, but reminds them that the animal moves very slowly and that they must therefore try to move the token on the circle as slowly as possible. Here, too, the examiner times the action. The quantitative score is based on the time it takes the child to complete the task.

The toddlers’ inhibitory control was assessed using the Fish (Usai et al. 2017a) task. The test is suitable for children aged between 2 and 6 years. The examiner shows the children a series of 14 sheets (two training boards), each displaying a small blue fish (the target, identified by a red dot) in the centre, flanked by other (green) fish (distractors) of the same size. The latter may be oriented in the same direction as the target (congruent condition) or in the

opposite direction (incongruent). The children's task is to indicate the food the blue fish will eat. The accuracy score is the result of correct answers given by the children only in the incongruent conditions.

The preschoolers' inhibitory control was assessed using the Stroop Day/Night (Usai et al. 2017a) task. This test is suitable for children aged between 3 and 5 years. It consists of two phases: a "control" phase, and a "test" phase. In the first phase, half of the 16 cards depict a chessboard, and the other half depicts an X. The chessboards are referred to by the examiner as "day" and the Xs as "night". After defining them, the children are asked to say "day" or "night" depending on which card they see. Once the children have understood the mechanism, the test begins, in which the examiner notes any naming errors (Stroop accuracy) and the time it takes the children to name all 16 cards presented (Stroop speed).

Thereafter, the test phase begins, in which the examiner defines the card depicting the moon as "day" and the card depicting the sun as "night". The test then continues in the same way as before. The accuracy score is derived from the difference between the correct answers recorded in the control phase and those obtained in the actual test phase. The speed score is derived from the total time, in seconds, taken to complete the control and test phases. The preschoolers' working memory was assessed using the Keep Track (Usai et al. 2017a) task. It is suitable for children aged between 4 and 6 years. After familiarising the children with the images in the example tables, the examiner explains that the task requires them to name the images one by one, depicted in different series (animals, clothes, means of transport, fruit, sky), and to remember the last image belonging to the category requested by the examiner (Keep Track accuracy). In the first three series, the children must remember the last picture seen in the target category; in the last three, more complex series, they must remember the last two pictures belonging to two target categories. To make the test less difficult, the categories to be remembered remain visible via a thumbnail at the bottom of each page. The examiner awards one point for each correct recall answer (in the case of two categories, one for each correctly recalled figure), half a point for a correct answer provided only after consulting the help table, which indicates the box with the figures in the requested category, and zero for incorrect answers.

Music Training

The musical training sessions were conducted by a qualified teacher, a specialist in early childhood music education. The educators and teachers from the classes involved were also included in the meetings as observers, with minimal intervention in the children's activities, as suggested by the

researchers. The training consisted of eight weekly sessions, each lasting 45 min, with groups of 20 children maximum, composed of 2 and 4-year-olds. The programme's immediate aims included introducing children to the world of music, and its broader goals included strengthening personal identity and fostering a sense of group and civic belonging.

To achieve these aims, specific developmental goals were established. These were: to improve attention, listening skills, and expressive awareness of the body and voice; to explore and experiment with the properties of sound; to develop sound-gesture coordination and fine motor skills; to recognise and reproduce basic rhythmic patterns, including through the reading of simple rhythmic and melodic scores; to stimulate creativity through improvisation; and to promote social awareness with group-based activities.

The training drew upon the Orff-Schulwerk approach (Piazza, 1979, 1983) and was organised around four main domains: musical awareness (i.e., familiarisation with musical instruments and genres), basic musical concepts (i.e., rhythm values, notes, and time signatures), rhythmic and pitch-related skills (i.e., ear training and the production of rhythmic and melodic patterns), and performance (i.e., improvisation and imitation using the voice and instruments).

Musical concepts were introduced through experiential learning and playful exploration. Activities included dance, guided movement, singing and vocal games, rhythmic and body percussion exercises, listening to and analysing musical pieces presented as stories by the musician, and reading and reproducing simple rhythmic scores. Children engaged with various instruments, such as xylophones, metallophones, recorders, and drums, alongside body percussion and vocal exploration, within a setting designed to support interaction, discovery, and collective creativity. The specific activities are presented in the Supplementary Materials, divided between eight meetings.

The activities were suitable for both 2- and 4-year-olds, with different levels of complexity that the children could freely choose according to their interests and abilities in completing a task. The music training was structured in this way to respond to the National Guidelines proposed by the Italian Ministry of Education (2017), which encourage actions promoting cooperation between nursery and kindergarten services, to enhance the well-being and inclusion of children, and a high-quality educational offer. This chimes with the paradigm of the educational services, which have evolved from being places of care to spaces of educational planning, where adults play a key role in promoting both the well-being and skills of children (Catarsi & Pourtois, 2011), in accordance with the Sustainable Development Goal of Quality Education proposed by the United Nations in 2015.

Data Analysis

The analyses were conducted using Jamovi software 2.3 (The Jamovi Project, 2022).

First, the potential associations between the outcome measures and maternal and paternal education (years of formal education) were examined, as well-established influential factors in developing lexicon and executive function abilities (Hoff, 2003; Noble et al., 2005). Because both were significantly associated with the variables investigated, they were summed in a single measure entitled “parents’ education”. After that, the means were calculated and transformed into z-scores.

Since many measurements did not follow a normal distribution, Levene’s test was conducted for each analysis of covariance, with parents’ education as covariate (ANCOVA), to assess the assumption of homogeneity of variances between groups. The choice of repeated-measures ANCOVA was based on two reasons. Firstly, Levene’s test indicated a violation of the assumption of homoscedasticity in a few cases (1/10 in the nursery and 3/10 in kindergarten); these violations were limited to specific time points and were not systematic across the different tasks or domains considered. Secondly, descriptive statistics and graphical inspection indicated approximately symmetrical distributions and comparable sample sizes between groups, conditions under which repeated measures ANOVA/ANCOVA are generally considered robust (Blanca-Mena et al., 2017).

Second, to assess the impact of the music intervention between pre- and post-training, a series of repeated-measures ANCOVA was carried out, with scores as dependent variables, Time as a within-subject factor, Group as a between-subjects factor, and the composite parental education measure included as a covariate. These analyses were run separately for toddlers and preschoolers.

Third, another repeated measures ANCOVA was performed, with parents’ education as the covariate, to compare the effect of the music training on the rhythmic abilities of the toddlers and the preschoolers, because the rhythmic skills were assessed with the same task. “Rhythm z-scores” were used to compare different ages.

Finally, partial correlations, with parents’ education as a covariate, were made to assess the association between rhythmic abilities, lexical skills, and executive functions at pre-training. These analyses were run separately for toddlers and preschoolers.

Results

Effects of the Music Training on Rhythm, Lexicon and Executive Functions

For the toddlers’ sample, Table 2 presents the descriptive characteristics of the scores of the tests conducted in the pre- and post-training assessment, divided into the training and waitlist control conditions.

Before conducting repeated measures of ANCOVAs, their robustness was checked using the homogeneity of variance test. Levene showed only one violation for the Rhythmic Imitation at the pre-training [$F(1, 44)=4.70, p=0.036$]. Given this confirmation of robustness and similar group sizes, analyses were performed without adjustment.

Next, the repeated measures ANCOVAs were performed, with parents’ education as the covariate. For the Rhythmic Imitation test, a significant effect of time [$F(1,36)=15.572, p<0.001, \eta^2p=0.302$], and a significant time-by-group interaction [$F(1,36)=5.174, p=0.029, \eta^2p=0.126$] were found. Figure 1 shows this tendency clearly.

The repeated measures ANCOVA between toddlers’ and preschoolers’ pre-post-training rhythmic ability did not reveal any statistically significant effect. However, Fig. 2 shows that the toddlers, on average, had lower scores in the pre-training phase and improved and came close to the average scores of the preschoolers in the post-training assessment.

Table 2 Means and standard deviations (in parentheses) for the toddlers’ training and waitlist control groups on each developmental domain test at pre- and post-training

Task(measure)	Pre-training M (SD)	Post-training M (SD)	Pre-training M (SD)	Post-training M (SD)
	Training Group		Waitlist Control Group	
Rhythmic reproduction (Rhythmic Imitation)	1.65 (1.29)	3.92 (2.30)	2.20 (0.95)	2.44 (2.41)
Lexical comprehension (PinG)	31.70 (5.36)	33.60 (5.55)	29.60 (5.52)	33.00 (4.70)
Lexical production (PinG)	19.40 (8.76)	22.00 (9.81)	12.40 (7.37)	15.40 (8.69)
Motor and inhibitory control (Circle Drawing)	0.01 (0.35)	0.28 (0.30)	0.07 (2.27)	0.21 (0.27)
Inhibitory control (Fish)	3.32 (1.66)	3.74 (1.98)	2.60 (1.67)	3.00 (1.57)

Fig. 1 Graph from Jamovi of the pre- and post-training mean scores of the Rhythmic Imitation task in the training group and waitlist control group

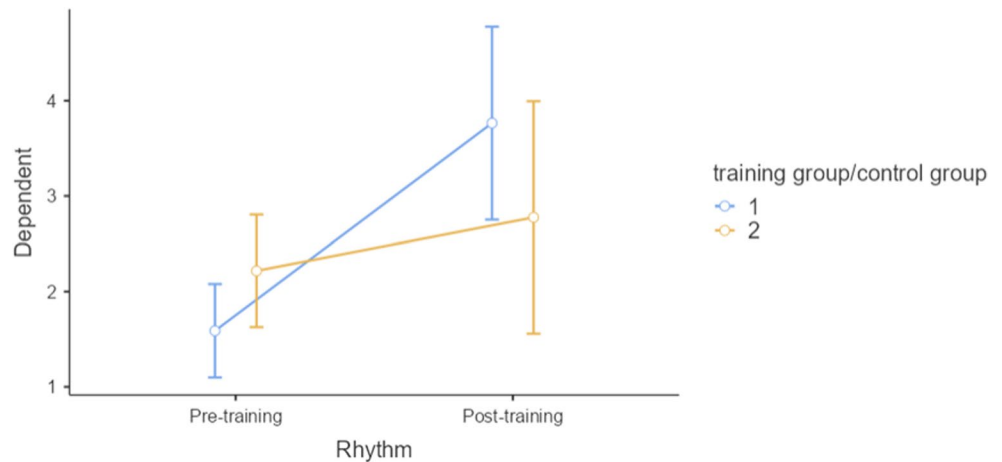
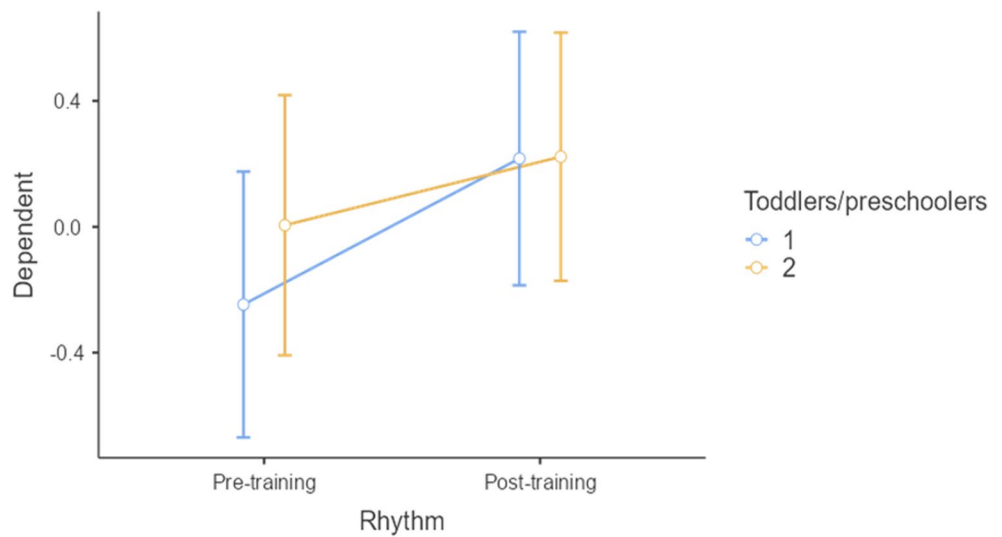


Fig. 2 Graph from Jamovi of the pre- and post-training mean scores in the Rhythmic Imitation task in the training group, divided by toddlers and preschoolers



Additionally, there was an effect of time and parents' education in the PinG comprehension scores [$F(1,49)=15.100, p<0.001, \eta^2p=0.236$; $F(1,49)=8.314, p=0.006, \eta^2p=0.145$]. The PinG production scores showed a significant effect of time [$F(1,49)=14.007, p<0.001, \eta^2p=0.222$], of group [$F(1,49)=4.480, p=0.039, \eta^2p=0.084$] and of parents' education [$F(1,49)=7.760, p=0.008, \eta^2p=0.137$]. Similarly, a significant effect of time was found for the Circle Drawing task, [$F(1,47)=14.200, p<0.001, \eta^2p=0.232$]. Otherwise, no significant effects were observed for the Fish task.

For the preschoolers' sample, Table 3 presents the descriptive characteristics of the scores of the tests conducted at the pre- and post-training assessments, divided into the training and waitlist control groups.

Before conducting repeated measures of ANCOVA, their robustness was checked using the homogeneity of variance test. Levene showed three violations for the Stroop accuracy at the pre-training, $F(1, 52)=6.61, p=0.013$, the Stroop accuracy, $F(1,52)=6.90, p=0.011$, and the Stroop speed

Table 3 Means and standard deviations (in parentheses) for the preschoolers' training and waitlist control groups on each developmental domain test at pre- and post-training

Task(measure)	Pre-training	Post-training	Pre-training	Post-training
	M (SD)	M (SD)	M (SD)	ing M (SD)
	Training Group		Waitlist Control Group	
Rhythmic reproduction (Rhythmic Imitation)	4.33 (2.67)	7.04 (3.12)	4.45 (3.25)	5.00 (2.66)
Lexical comprehension (PPVT)	33.40 (20.20)	41.70 (24.40)	37.30 (21.50)	44.50 (21.40)
Inhibitory control accuracy (Stroop Day/Night)	1.55 (2.90)	0.19 (0.65)	1.22 (1.48)	0.30 (1.69)
Inhibitory control speed (Stroop Day/Night)	-3.00 (2.54)	-0.14 (1.09)	-2.52 (2.21)	-1.13 (1.96)
Working memory accuracy (Keep Track)	2.40 (1.71)	4.94 (2.27)	2.13 (1.52)	3.24 (1.90)

at the post-training, $F(1,52)=4.23, p=0.045$). Given the robustness demonstrated and similar group sizes, analyses were performed without adjustment.

Next, the repeated measures ANCOVAs were performed, with parents' education as the covariate. For the Rhythmic Imitation test a significant effect of time [$F(1,36)=4.85$, $p = 0.034$, $\eta^2p=0.119$], a significant time-by-group interaction [$F(1,36)=4.22$, $p = 0.047$, $\eta^2p=0.105$], and a significant effect of the parents' education [$F(1,36)=6.45$, $p = 0.016$, $\eta^2p=0.152$] were found. Figure 3 shows this tendency clearly.

Moreover, from PPVT, a significant effect of time and parents' education was also discovered [$F(1,40)=13.36$, $p<0.001$, $\eta^2p=0.250$; $F(1,40)=30.79$, $p<0.001$, $\eta^2p=0.435$]. For Stroop accuracy, only a significant effect of time was observed [$F(1,42)=6.36$, $p = 0.016$, $\eta^2p=0.131$]. On Stroop speed, the following findings emerged: a significant effect of time [$F(1,40)=42.51$, $p<0.001$, $\eta^2p=0.515$], a significant time-by-group interaction [$F(1,40)=9.52$, $p = 0.004$, $\eta^2p=0.192$], and time-by-parents' education interaction [$F(1,40)=5.40$, $p = 0.025$, $\eta^2p=0.119$]. Figure 4 shows the large increase in the Stroop speed of the training group from pre- to post-training, and a smaller increase in the waitlist control group over the same period.

The Keep Track accuracy test revealed a significant effect of time [$F(1,42)=34.20$, $p<0.001$, $\eta^2p=0.449$] and a significant time-by-group interaction [$F(1,42)=5.33$, $p = 0.026$, $\eta^2p=0.113$]. Figure 5 shows the increase in the Keep Track accuracy of the training group from pre- to post-training, and a smaller increase in the waitlist control group in the same period.

Associations Between Rhythm and Lexical/EF Competencies

No significant correlations were found in the toddlers' sample at pre-training between Rhythmic Imitation, Picture Naming Game, Circle Drawing, and Fish tasks ($0.490 < p < 0.911$). In the preschoolers at pre-training, on the other hand, a significant correlation was found between the Rhythmic Imitation test results and PPVT ($r=0.334$; $p = 0.033$), Stroop speed ($r=0.439$; $p = 0.005$), and Keep Track ($r=0.366$; $p = 0.019$).

Fig. 3 Graph from Jamovi of the pre- and post-training mean scores of the Rhythmic Imitation task in the training group and waitlist control group

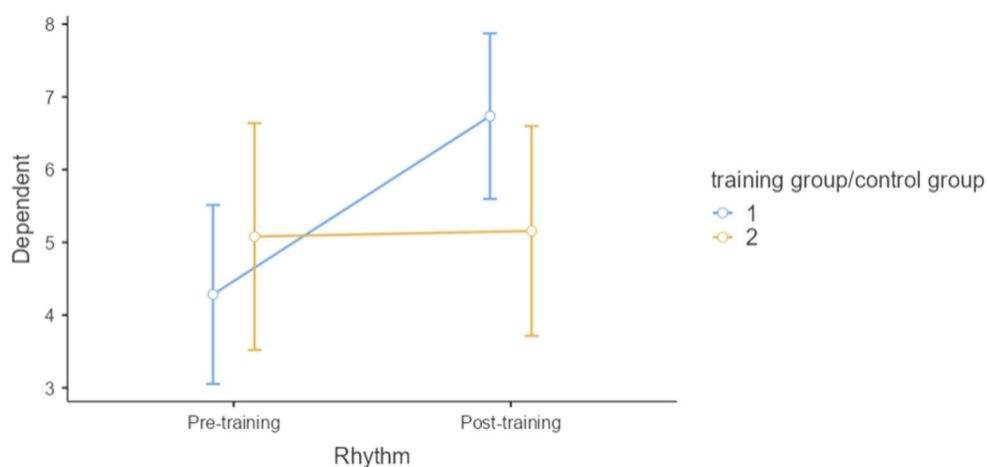
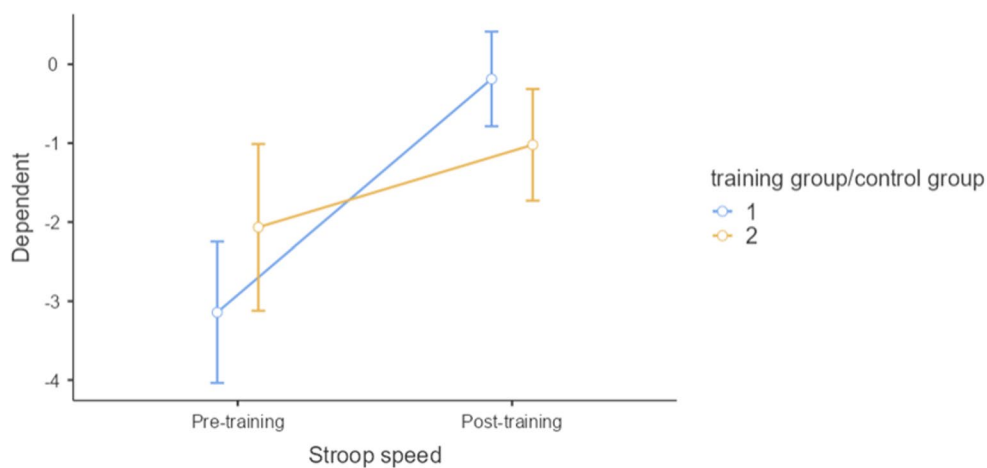


Fig. 4 Graph from Jamovi of the pre- and post-training mean scores of the Stroop speed task in the training group and waitlist control group



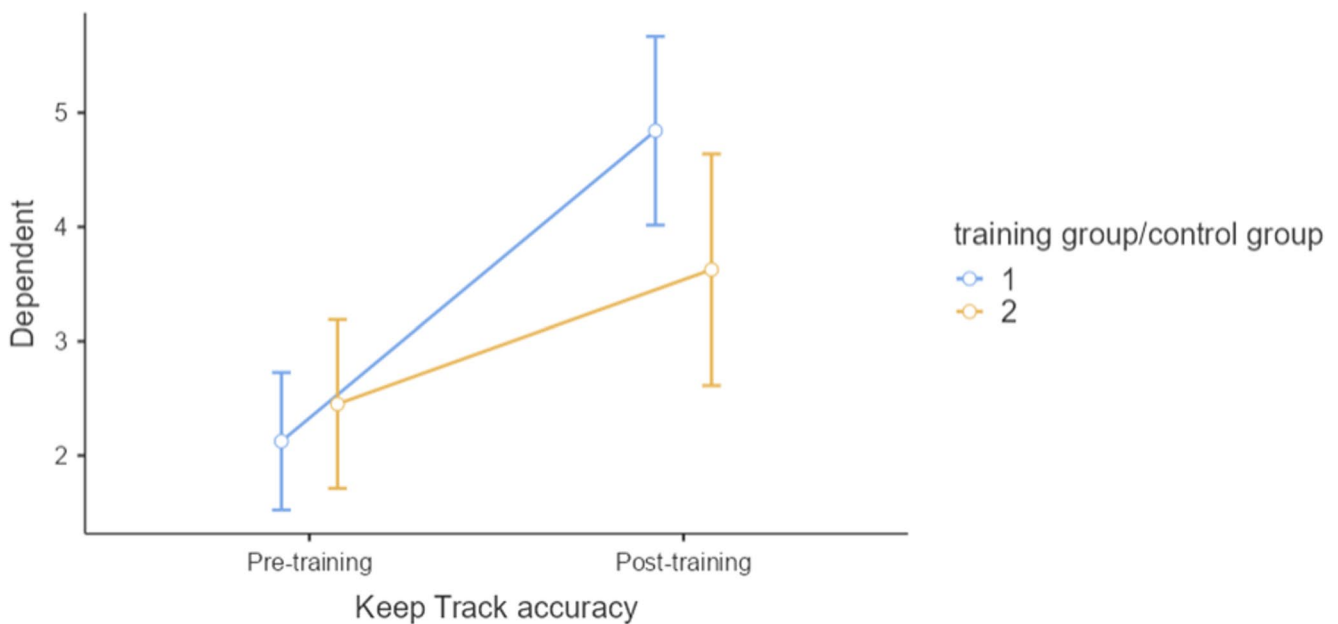


Fig. 5 Graph from Jamovi of the pre- and post-training mean scores of the Keep Track accuracy task in the training group and waitlist control group

Discussion

This study aimed to evaluate the effectiveness of an 8-week music training programme in supporting the development of rhythmic, lexical, and EFs in children aged 2 and 4 years, with particular attention given to age-related differences and inter-domain associations. The findings add important information to the existing literature, showing that rhythmic, lexical, and EF skills followed similarities and differences in developmental patterns and in the effectiveness of the music training.

Effects of Training on Rhythm, Lexicon, and EFs

Rhythmic competence improved significantly in both age groups following the training, confirming the hypothesis of the intervention's effectiveness in this domain. In fact, the experimental groups exhibited a significant increase from pre- to post-intervention. It supports the hypothesis of early plasticity in the rhythmic system, consistent with findings by Hannon and Trehub (2005a, b), who demonstrated that infants are sensitive to a wide range of rhythmic patterns and capable of acquiring new temporal structures, mainly when supported by embodied and relational experiences (Phillips-Silver & Trainor, 2005). The improvement in rhythmic skills confirms the validity of the musical training in developing rhythmic competence. In addition, no significant age-related differences for rhythm competencies emerged between toddlers and preschoolers, even though the younger group started from a lower average position and

grew to almost the level of the older sample by the end of the music intervention. Although toddlers' and preschoolers' rhythmic competencies are quite different (Drake et al., 2000; Endedijk et al., 2015; Kirschner & Tomasello, 2009; Provasi & Bobin-Bègue, 2003; Rizonico & Oddi, 2021; Yu et al., 2022), the toddlers' abilities may have improved more because the activities were mostly linked with movement, confirming the hypothesis of the role of motor skills and synchronisation in the development of rhythmic ability (Phillips-Silver & Trainor, 2005; Tichko et al., 2022).

Conversely, no training effects emerged on the lexical skills of the children of both age groups. Specifically, lexical comprehension and production showed an increment associated with age-related growth trajectories and parental educational level. It confirms previous studies on the positive impact of high parental educational levels on children's vocabulary development (e.g., Hoff, 2003). The lack of an apparent training effect on language may result from the brevity or the low frequency of the intervention, differing from more frequent and longer-term programmes reported in the literature (e.g., Bolduc et al., 2020; Shen et al., 2019; Vidal et al., 2020). Lexicon acquisition is, in fact, a complex process that may take longer to consolidate and yield statistically significant effects. This should be investigated in further research.

For the EF trajectories, the music training showed different effects in the two age groups. Improvements in the executive functions, particularly inhibitory control speed, and working memory accuracy, were observed only in preschoolers, while in the toddlers, the music intervention produced

no significant additional effect beyond neurocognitive time-related development. These findings for preschoolers correspond to research indicating that musical interventions can enhance executive functions such as inhibition and working memory (Bowmer et al., 2018; Bugos & DeMarie, 2017; Shen et al., 2019). Notably, parental background influenced response speed but not working memory, suggesting the latter may be more sensitive to targeted cognitive stimuli such as music and less dependent on sociocultural factors. However, the lack of effect for younger children indicates the need for further research on the impact of musical training on lexicon and executive functions, focused on the 0–3 age group, which remains underrepresented in the literature.

Rhythm as a Transversal Skill: Associations with Lexicon and EF

Regarding the relationship among rhythm, lexicon, and EFs, conflicting trends were observed when comparing toddlers and preschoolers.

In the toddlers, no correlations appeared between rhythm and either lexicon or executive functions. This might raise questions about the role of rhythm as a transversal competence, contrary to previously cited literature (Frischen et al., 2019; Tierney & Kraus, 2013). However, those studies focused on populations older than 3-year-olds. Future research should, therefore, investigate the interplay between rhythm, lexicon, and executive functions in the 0–3 age population.

A relationship did appear in the preschoolers between rhythm and each of the lexicon, inhibitory control speed, and working memory, supporting the idea of a relationship between rhythm and other cognitive domains, as reported in the literature (Magne et al., 2005; Miendlarzewska & Trost, 2014). However, despite these findings, future research is needed to offer greater understanding of the nature of the relationship between these variables.

Limitations and Practical Implications

Despite the positive outcomes, the study has four main limitations. First, because the same music training sessions were delivered simultaneously to both toddlers and preschoolers, it is not possible to determine whether the interaction between children of different ages contributed to the results. Second, the lack of follow-up data prevents any conclusions about the long-term effects of the intervention. Third, the few results in lexical development could be attributable to the intervention's limited duration and frequency; vocabulary acquisition is, in fact, a complex process that may require more time to consolidate and yield statistically significant effects. Fourth, due to the

absence, to our knowledge, of standardised and norm-referenced rhythmic reproduction tests for children between 2 and 4 years of age, an adapted imitation-based task was employed; and the results should therefore be interpreted as indicators of emerging rhythmic skills rather than stable rhythmic competence.

Regarding the practical implications, the training was conducted in an integrated manner for several reasons, including those related to the Italian National Guidelines (2017), which call for quality education (United Nations, 2015) that also includes musical activities, recognised as capable of generating well-being and inclusion, while also allowing nurseries and kindergartens to work on the integration of the two educational systems. That said, music interventions can be created that involve both groups, offering the same activity frameworks, while tailoring the demands to the children's abilities and developmental potential, as was done in this training.

In conclusion, the musical intervention implemented in this study is a promising approach to supporting child development, taking into account the children's individual characteristics. Beyond fostering individual growth, such interventions may significantly enhance the quality of educational services, particularly within an integrated 0–6 year perspective (Italian Ministry of Education, 2017), enriching learning environments (United Nations, 2015), children's well-being and inclusion, and supporting the professional role of early childhood educators and teachers.

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Declarations

Compliance with Ethical Standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Ethics Committee of the University of Verona (ethical approval code: 2023_35).

Informed consent Written informed consent was obtained from the parents of children involved in the research.

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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