

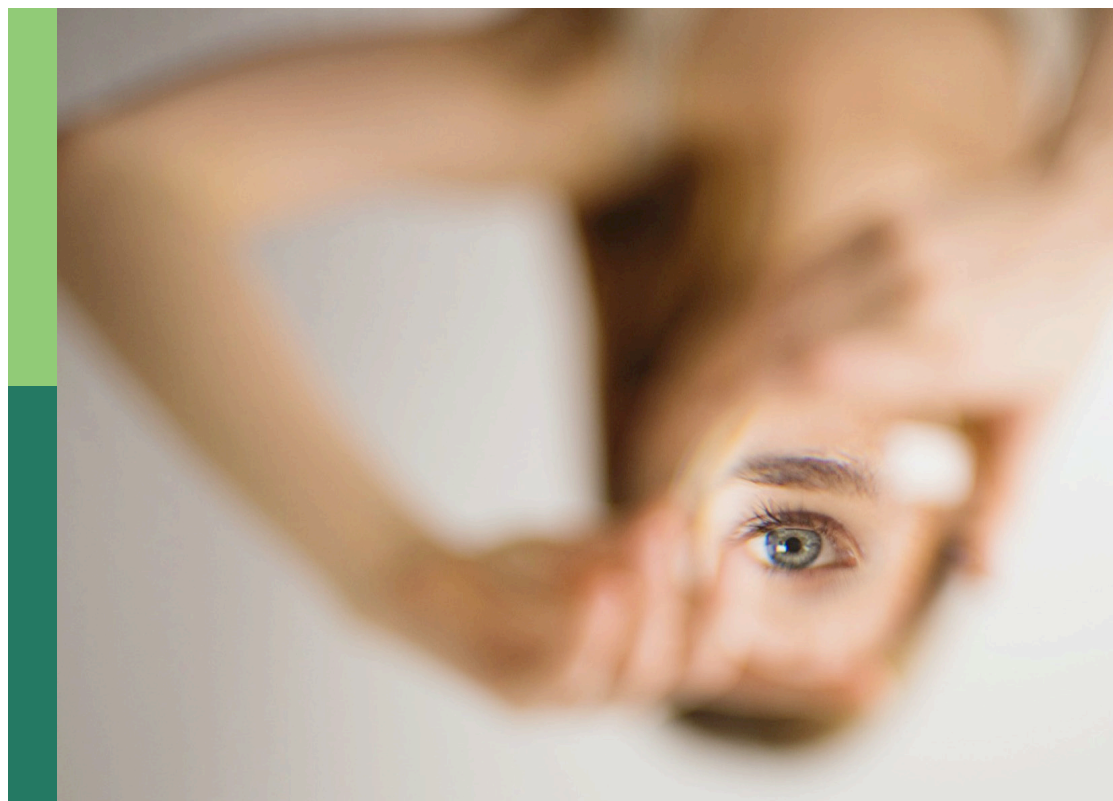
Medical neurohumanities: sharing insights from medicine, neuroscience and music in pediatric care

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Medical neurohumanities: sharing insights from medicine, neuroscience and music in pediatric care

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Editorial: Medical neurohumanities: sharing insights from medicine, neuroscience, and music in pediatric care

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neonatal intensive care unit (NICU), neurohumanities, music therapy, medicine, pediatrics, care

Editorial on the Research Topic

[Medical neurohumanities: sharing insights from medicine, neuroscience and music in pediatric care](#)

In recent years, the concept of “Medical Neurohumanities” has emerged as a vibrant interdisciplinary field, blending the insights of medicine, neuroscience, and the humanities to deepen our understanding of health, illness, and healing. This Research Topic, “Medical Neurohumanities: Sharing Insights from Medicine, Neuroscience, and Music in Pediatric Care,” brings together diverse perspectives that showcase how integrating knowledge across disciplines can meaningfully enrich pediatric care, particularly for vulnerable populations such as preterm infants, critically ill children and their families.

Neurohumanities have been debated and increasingly applied in medicine, with the vital relationship between music sciences, music therapy, and pediatric care remaining underexplored. On the one hand,

“[...]neurology attempts to understand the biological basis of our humanity. At the same time, neurological conditions profoundly impact our humanity. The practice of neurology requires a curiosity about the person, the disease, and the ability to listen to and hear stories.”

- Carandang (2025; online)

On the other, neurohumanities re-emphasize the humanistic aspects of medical practice and investigate the importance and influence of perspectives, behaviors, and feelings related to the practice of neurology and medical practice at large. Furthermore, they raise self-awareness and the impact of our perspectives on others and explore the intersection of art and neurology medicine and how neurology positively impacts the world.

As our understanding of the young brain expands, creating a shared lexicon that connects music, neuroscience, technological innovations, pediatrics, and healthcare is crucial. By fostering interdisciplinary collaboration, we can deepen our comprehension of the working-mechanisms of music therapy and music medicine for pediatric patients. Sharing insights, approaches, methods and interventions promotes interdisciplinary understanding, enabling the development of more effective, patient- and family-centered healthcare strategies that consider ethical aspects, shared therapeutic goals, care and medical responsibilities. This will lead to a de-disciplined approach, where the expert identifies the boundaries of their discipline, to reach beyond that border toward new frontiers in any given field.

This Research Topic aimed to foster dialogue between scientific and artistic disciplines and highlight innovative approaches where neuroscience, clinical medicine, therapy and music intersect to improve (neuro)developmental as well as clinical outcomes and humanize healthcare experiences. By bridging gaps between empirical evidence and clinical practice, the contributing articles offer new lenses through which pediatric healthcare and development can be viewed, supported, and enhanced.

Several contributions focus on the early developmental period and the unique needs of neonates and their caregivers. For example, [Hugoson et al.](#) present the pioneering work on Creative Music Therapy (CMT) in neonatal intensive care units (NICUS), supporting parent-infant bonding and neurodevelopmental trajectories in preterm infants ([Haslbeck et al., 2023](#); [van Dokkum et al., 2020](#); [Bos et al., 2021](#)). Their study emphasizes that parental singing during kangaroo care, primarily when facilitated by a trained music therapist, strengthens the parents' sense of coherence by promoting experiences of comprehensibility, manageability, and meaningfulness. Interestingly, this is the first study that interviewed singing parents of an intervention group which received CMT and the control group without CMT support. Parents who received CMT reported a deeper understanding of how singing facilitates attachment and enhances self-esteem, reflecting improvements in perceived manageability and comprehensibility. While parents in the control group also expressed joy in singing and noted positive effects on family wellbeing, these experiences were less pronounced, not described as a healing experience and catharsis as in the CMT group and started far later during the NICU trajectory since many parents were not able to raise their voice for singing during the first weeks of their NICU stay. However, particularly during these first weeks, parental anxiety, stress and trauma may evolve and imprint so that therapeutic support, such as CMT, may act as a preventive health intervention for these families as indicated in [Kehl et al. \(2021\)](#). Complementing this, [Dewan et al.](#) examined the impact of live music therapy on the parental stress levels of preterm infants during the neonatal care period. Their findings highlight how music therapy can reduce subjectively perceived parental stress and more objective indicators of stress, such as parental cortisol levels.

While the improvements on parent child bonding are compelling, there are additional benefits from music interventions on emotional and neurodevelopmental outcomes in preterm infants. [Filippa et al.](#), has tracked infants at 12 and 24 months post

intervention revealing enhancements in emotional regulation and neurodevelopmental milestones, underscoring the importance of early auditory stimulation in at risk-populations.

The Euterpe music therapy methodology has been introduced as a structured approach to integrating music therapy in pediatric care ([Liuzzi and D'Arienzo et al.](#)). This methodology includes detailed procedural algorithms designed to standardize and optimize music therapy interventions, ensuring consistency and efficacy in clinical settings.

From a broader theoretical perspective, [Stige \(2012\)](#) offers a conceptual framework for “musicking” in healthcare contexts, linking neurobiological mechanisms with psychosocial processes. He advocates for a relational understanding of music as a co-created, embodied activity that transcends traditional therapy models, opening possibilities for its application in pediatric and family-centered care.

These articles illuminate the transformative potential of the Medical Neurohumanities in pediatric care. They illustrate how integrating arts-based practices, relational neuroscience, and humanistic inquiry can not only optimize developmental outcomes but also rehumanise healthcare environments that are often dominated by technology and protocols.

Innovative research exploring the feasibility of using clinical EEG to recognize music in children, demonstrates the potential for non-invasive monitoring of auditory processing. This approach as is described below, could pave the way for personalized music therapy strategies tailored to individual neural processes.

Three critical tensions persist despite the demonstrable clinical promise illustrated across this Research Topic. First, methodological heterogeneity—ranging from the single-center, low-powered EEG feasibility study by [Bower et al.](#) to the highly “protocolized” yet context-bound Euterpe algorithms detailed by [Liuzzi and D'Arienzo et al.](#) and [Liuzzi, Bompard et al.](#)—impedes meta-analytic synthesis and obscures dose–response relationships. Second, outcome measures remain fragmented: while [Dewan et al.](#) document acute biobehavioural stress attenuation in parents, [van Dokkum et al.](#) reveal downstream respiratory and mood sequelae linked to NICU stress that current interventions leave mostly unaddressed. Third, scalability is constrained by limited implementation science; the carefully staged guidelines for early parental vocal contact advanced by [Filippa and Kuhn](#), although pragmatic, have yet to be benchmarked against health-economic or cross-cultural metrics.

Consequently, future research within Medical Neurohumanities must transition from proof-of-concept to precision, leveraging digital phenotyping ([Insel, 2017](#)), multimodal neuroimaging ([Papatzikis, 2024](#)), and federated data repositories with advanced Machine Learning algorithms to both establish reproducible biomarkers of musical efficacy and inform novel interventions and control the clinical environment on the ward and at bedside ([Jaschke, 2025](#); [Kunikullaya et al., 2025](#); [Jaschke et al., 2024](#); [Jaschke and Bos, 2023](#)). Multi-site adaptive trials—anchored in standardized clinically relevant core outcome sets and harmonized intervention taxonomies—could clarify the timing and sensitivity periods across the developmental trajectory, as suggested by the 12- and 24-month emotional modulation evidenced by [Filippa et al.](#) In parallel, implementation

laboratories should interrogate contextual moderators, integrating caregiver-reported or family-centered feasibility and family health indicators with real-time physiological analytics to inform just-in-time adaptive interventions. Finally, the field would benefit from consensus on an ontological lexicon that unites neuroscientific constructs (e.g., predictive coding, interoceptive attunement) with humanities-derived notions of meaning-making, thereby fulfilling the transdisciplinary mandate of this Special Research Topic and accelerating the translation of embodied musical experiences into equitable, sustainable pediatric care.

This Research Topic invites healthcare professionals, researchers, and artists alike to envision new paradigms of pediatric care—ones that are attuned to the biological, emotional, and relational complexities of early human life. As the field of Medical Neurohumanities continues to evolve, it holds promise for fostering more holistic, compassionate, and effective models of care for children and their families.

This Research Topic underscores the growing recognition of the intersection between the arts and sciences in pediatric care. By highlighting the therapeutic benefits of music and auditory interventions, it advocates for a more holistic approach to pediatric healthcare—one that considers children's emotional and developmental needs alongside traditional medical treatments. Integrating music therapy into clinical practice enriches the healthcare experience for parents and families and opens avenues for future research and innovation in pediatric and neonatal care.

We hope this Research Topic catalyzes further interdisciplinary collaborations and inspires innovative practices that honor both the science and the art of healing.

Author contributions

AJ: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration,

Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. EP: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. FH: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

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Music therapy modulates mothers' perception of their preterm infants

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Premature birth imposes considerable challenges on the preterm infant, but also challenges the mother, who may not yet be prepared for motherhood and encounter psychological stress during the post-partum period. This secondary analysis of a prospective randomized controlled trial (RCT) aimed to investigate how mothers perceive their preterm infants. We surveyed 33 mothers of preterm infants born before 32 weeks of gestation, who were participating in an RCT on music therapy. We employed the neonatal perception inventory (NPI), an instrument designed to assess the mother's perception and expectations regarding her infant immediately after birth. Infants were randomly assigned to either standard care (control group) or standard care plus music therapy (intervention group). Eighteen mothers from the intervention group participated in the survey (mean age 34.1 ± 4.6 years) and 15 mothers from the control group (mean age 29.6 ± 4.2 years). At the time of the infant's hospital discharge, mothers rated their expectations of how they felt a baby should behave (NPI I) and how they perceived their own infant (NPI II). The NPI score difference was calculated by subtracting the NPI II from the NPI I. Mean NPI I scores were comparable between both groups, but NPI II scores in the intervention group were better [18.0, 95% confidence interval (CI) 16.6–19.4] than in the control group (19.1, 95% CI 18.0–20.3). The relative probability of mothers rating their own baby as better than average was 1.94 (95% CI 1.00–3.79) for mothers whose infants received music therapy. These findings suggest that music therapy in the neonatal intensive care unit can positively influence mothers' perception of their hospitalized preterm infant.

KEYWORDS

music therapy, neonatology and pediatric intensive care, neonatology, music, preterm infants, premature infants, neonatal intensive care unit

1. Introduction

The transition to motherhood, marking the onset of the mother-child relationship, represents a crucial phase of adjustment within a family, entailing important changes in a mothers lifestyle and daily routines (Price et al., 2000; Deave et al., 2008). This transition and adaptation to the new role can pose substantial challenges, even for full-term infants' mothers.

However, preterm birth can exacerbate these challenges: Mothers of preterm infants are at increased risk of experiencing negative emotions toward their baby in the first few months compared to term infants' mothers, possibly due to reduced early contact with their infant (Wolf et al., 2002; Henderson et al., 2016). They frequently perceive their baby as more difficult than the average infant and use more negative adjectives to describe their baby. At the same time, it is well-established that a mother's postnatal perception of the infant and the quality of the mother-infant bond play a major role in the well-being of mothers and their newborns (Smorti et al., 2020; Ahmadinezhad et al., 2022). While a positive maternal perception during the first months of life does not completely prevent developmental difficulties of the infant, the absence of a positive maternal perception of a newborn is associated with emotional development issues in the child (Broussard, 1997).

Typically, premature infants are immediately separated from their mothers after birth to ensure optimal medical care (Ncube et al., 2016). In today's neonatal intensive care units (NICUs), the challenge is to provide the best possible medical developmental care for a preterm infant and at the same time to support mothers in caring for and bonding with their infant (Tilokskulchai et al., 2002; Aagaard and Hall, 2008). It is undeniable that mothers of extremely preterm infants experience a higher level of psychological distress during the period immediately after the birth than mothers of full-term babies (Holditch-Davis et al., 2003). However, the adaptation to the premature mother's role can be promoted by empowering mothers to cope with negative experiences and emotions, especially in the NICU (Heydarpour et al., 2016).

Therefore, it is important to identify therapeutic interventions aimed at alleviating possible stress symptoms in the infants (Kobus et al., 2021a) and their mothers, thereby promoting a positive mother-child relationship (Benzies et al., 2013). Research has shown that targeted interventions such as music therapy can help and support mothers of preterm infants to establish positive parenting routines that are beneficial for themselves and their babies (Lau et al., 2020). Music therapy is an individualized and family-integrated therapy approach (Haslbeck and Bassler, 2020), offering various benefits for preterm infants and their parents (Ettenberger et al., 2016). By including the parents in the music therapy sessions, they can establish closer contact with their infants (Haslbeck, 2014; Ettenberger et al., 2016). Furthermore, music therapy serves as a stress-reducing intervention capable of not only temporary stabilization of a preterm infant (Standley, 2012), but exerting positive effects on the mother's behavior and emotions (Kobus et al., 2022c). Music therapy in the NICU reduces symptoms of anxiety and depression in couples during their NICU stay (Kehl et al., 2020). Parents perceive music therapy as a positive, supportive resource for themselves and their infants, which alleviates challenges faced the families during the difficult early days in a NICU (van Dokkum et al., 2020; Kobus et al., 2021b).

However, it remains unknown whether music therapy in preterm infants has an impact on how mothers perceive their infants. The aim of our study was to investigate the effect of live music therapy in the NICU, provided from the second week of life until hospital discharge, on mothers' perception of their preterm infants. We used the neonatal perception inventory (NPI) to assess how mothers of infants born <32 gestational weeks perceived their own infant compared to their expectation of an average baby at the time of hospital discharge. These analyses expand the understanding of music therapy for preterm

infants on maternal stress levels, building upon previously published research from the same group of mother-infant pairs, which showed that music therapy reduces depressive symptoms and distress in mothers during their infants' NICU stay (Kobus et al., 2022c).

2. Methods

2.1. Study design

Mothers of preterm infants born before 32 weeks gestational age at the neonatal intensive care unit of the University Hospital Essen (Germany) between January 2020 and May 2021 who were participating in a randomized controlled trial (RCT) on music therapy in preterm infants filled out the Neonatal Perception Inventory (NPI) at the infants' discharge from hospital. Fifteen months after the beginning of a randomized controlled trial on the effect of music therapy on preterm infants' short- and long-term outcomes (German Clinical Trials Registry number: DRKS00025753), the survey was added to the study protocol and mothers of all subsequently included infants were prospectively surveyed. A previous study using the same cohort of mothers and infants investigated the impact of music therapy on maternal distress as measured by Center for Epidemiologic Studies Depression Scale (CES-D) and Impact of Events Scale-Revised (IES-R) (Kobus et al., 2022c). The present study examines the effect of music therapy on mothers' perception of their infant at hospital discharge, a parameter that is a correlate of mother-infant connectedness (Holditch-Davis et al., 2007; Nicolaou et al., 2009).

2.2. Infant eligibility and recruitment for the randomized controlled trial

Infants born between January 2020 and May 2021 at the University Hospital Essen <32 weeks gestational age without congenital hearing disorders, intraventricular hemorrhage grade III after Papile, periventricular infarction or cerebral malformations were eligible for participation in the main study (Kobus et al., 2022b). The declaration of consent was signed by the parents at a minimum age of 72 h and a maximum age of 7 days of their infant. The randomized controlled trial was approved by the local ethics committee of the medical faculty of the University of Duisburg-Essen (18-8035-BO).

2.3. Randomization and music therapy intervention

In the main study, eighty clinically stable preterm infants were recruited and randomized. Randomization was carried out by one of the investigators (MD, MVD, NB, SK) immediately after inclusion into the trial by opening a numbered sealed envelope that contained information about the randomization group (standard care or standard care plus music therapy). Prior to the start of the study, a randomization list (allocation 1:1, block randomization with blocks of 10) was created and all envelopes prepared.

Forty stable infants of the intervention group received individually live-performed music therapy from a qualified music therapist in addition to standard medical care twice per week until

their hospital discharge (Kobus et al., 2021a, 2022c). During a session with a duration of about 10–15 min, the child was in the incubator, in a warming bed or had direct physical contact with the parents. Based on the reactions of the infant and synchronized with the respiratory pattern, the music therapist sang improvised melodies or played soft tones with the instrument Sansula throughout the entire session. The Sansula is an instrument which creates an enveloping soft sound. The tones were played at low and soft volume and the tempo adjusted to the breathing rhythm of each individual infant. The faster the breathing rhythm, the lower the tempo frequency of the tones so that the infants listened to calm music. The music was improvised individually for each infant. During the intervention, infants remained in the position they had been in before the session (incubator, heating bed, bed or on their mother's chest/arms). At the beginning of the music therapy session the therapist sat or stood next to the infant and began to play or sing a note. This note sounded for about 3 s, followed by a silence of about 3 s. The next tone then sounded at a different tone level. The periods of silence were gradually reduced within the first 5 min. Depending on the infants breathing rhythm, up to 30 tones per minute were played. If the breathing rhythm was high, the tones were synchronized with every second or third breath to calm down the infant. Usually, after a maximum of three tones there was a pause corresponding to the length of one or two tones. During the last 5 min of the session, the tempo was reduced again, and the breaks were lengthened. The pitch lowered at the end and the final note was a deep tone. Parents received the delivered music without active participation. All clinical data of the preterm infants and their mothers were analyzed and the mothers' presence during an intervention was documented.

2.4. Neonatal perception inventory

The Neonatal Perception Inventory (NPI) was developed by Broussard and Hartner to measure mothers' perception of their own neonate compared to their expectations of an average baby shortly after birth (Povedano et al., 2011). The NPI assesses six categories (crying, feeding, spitting, elimination, sleeping and predictability) on a five-point Likert scale, with 5 being the worst and 1 the best score. These items reflect the functioning of the mother-infant dyad during the neonatal period (Broussard and Hartner, 1971) and mothers provide their own baseline data by rating their own infants (NPI II Score) and a hypothetical average baby (NPI I score) (Broussard and Hartner, 1970; Povedano et al., 2011). The NPI II Score (own baby) is then subtracted from the NPI I score (average baby) to form the total score (NPI score difference).

The NPI scores I and II provide the parents perception about their own infants (NPI II Score) and a hypothetical average baby (NPI I score). It is important to assess not only the difference but also the absolute values, as the intervention might have modulated not only the perception of the own baby but also the expectation. The NPI score difference reflects the risk of later socioemotional problems in childhood, whereas the NPI II score was the most stable in a validation study (Camp, 1982).

An NPI score difference below zero implies a negative perception (negative direction), in which the mothers perceive their own infant to be more difficult than the average baby. A difference greater than

zero (positive direction) implies a positive perception of their own infant being less difficult than the average baby, which is associated with a low risk of later socioemotional problems in childhood (Palisin, 1981).

The five-point Likert scale of NPI has been validated, with the NPI II proving most robust (Camp, 1982).

2.5. Outcomes

The primary outcomes were mothers' mean NPI scores and mean score differences at the infant's hospital discharge in the intervention and control group and the difference between groups. Secondary outcomes were the proportion of own babies rated better than the expected average and the relative "risk" (= probability) of rating the own baby better than average in each group. Additionally, mean values for subscores of the NPI were calculated.

2.6. Statistical analyses

Categorical variables are presented as counts and relative frequencies. Continuous variables are presented as mean and standard deviation (SD) or 95% confidence intervals (CI) if evenly distributed and as median with interquartile range (IQR) if skewed. We analyzed the mothers' NPI I and II total scores, score differences between NPI I and NPI II and the scores of the six sub-categories crying, feeding, spitting, elimination, sleeping and predictability. For the main outcomes (NPI I and II and NPI score difference), mean and 95% CIs were calculated. To adjust for differences in NPI I, an analysis of covariance was carried out as a sensitivity analysis using a generalized linear model.

Effect sizes were calculated according to Cohen [Cohen's $d = (M_2 - M_1)/SD_{\text{pooled}}$] in order to provide an objective estimation of the strength of effect in addition to the crude and adjusted means. The relative "risk" (= probability) of having a positive direction in the perception of the own baby compared to average babies between the two groups was calculated using an unadjusted linear model.

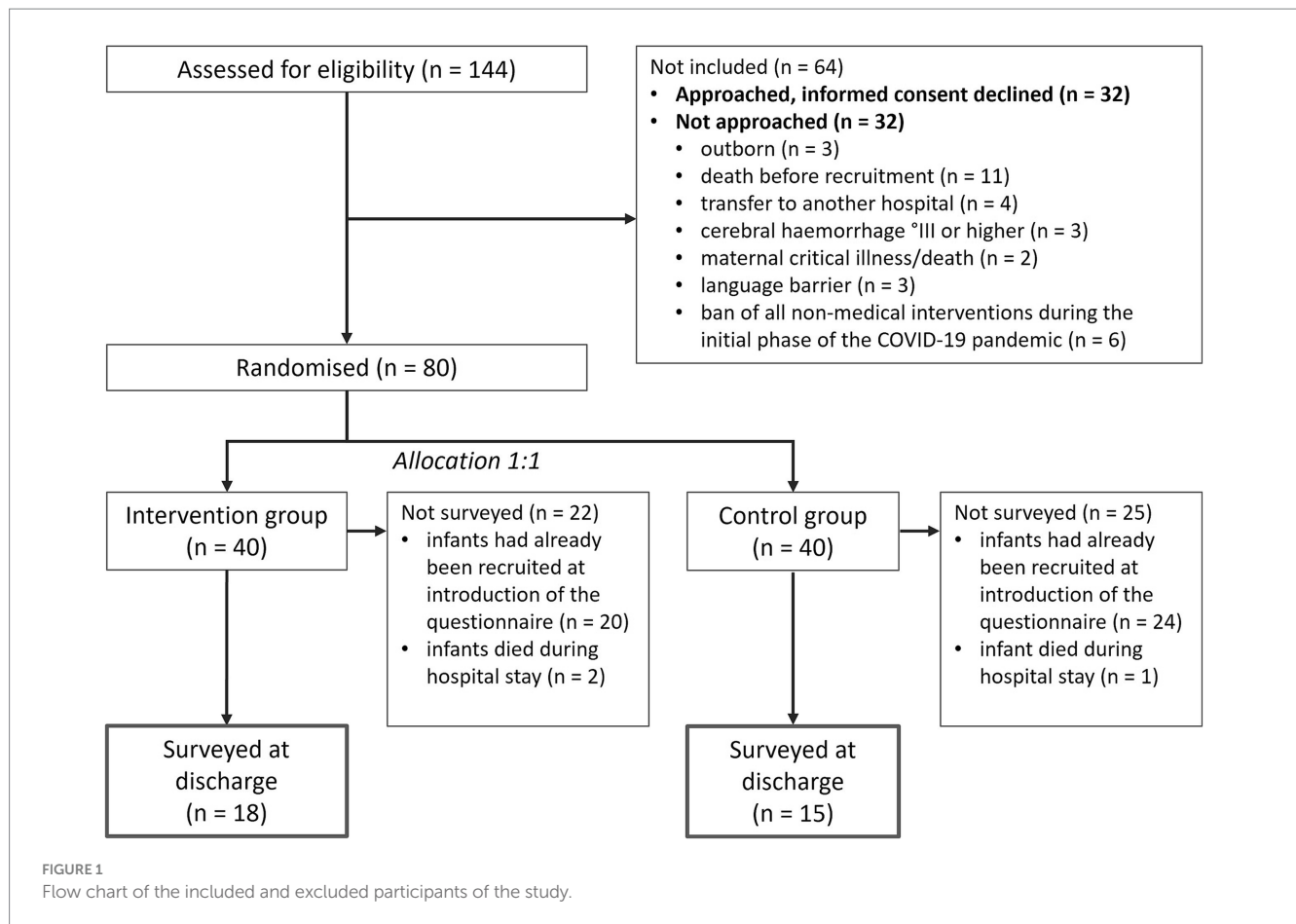
SAS Enterprise Guide 8.4 (SAS Institute Inc., Cary, NC, United States) was used to perform statistical analyses and produce figures.

3. Results

3.1. Participants

During the period of the main study from October 2018 to May 2021, 144 premature infants born at <32 gestational weeks were screened for eligibility (Figure 1). Eighty infants were randomized to either the intervention or the control group.

The NPI questionnaire was added to the main study beginning at the 45th of 80 infants, leading to 36 infants' mothers to potentially be included in the NPI analysis. Because three infants died before discharge (Figure 1), 33 infants (Table 1) and their mothers (Table 2) were included for the NPI analysis. The infants of the control group had longer median hospital stays, in spite of similar gestational ages and baseline characteristics at birth (Table 1).



A total of 286 music therapy sessions were conducted in the intervention group between corrected gestational ages of 24 + 5 and 42 + 1 weeks. The mean duration of each music therapy session was 29.6 min (range 10–50 min), with parents present in 105 (37%) sessions. On average, infants received six interventions together with their mother.

3.2. Neonatal perception inventory

The NPI I score did not differ between mothers whose infants received music therapy and mothers whose infants did not. Regarding the mothers' perception of their own infant, NPI II scores in the music therapy group were lower (=better) than in the control group [18.0 (95% CI 16.6–19.4) vs. 19.1 (95% CI 18.0–20.3)] (Table 3 and Figure 2). The mean differences between NPI I and II were larger (= more positive) in mothers with music therapy for the overall score difference (Table 3) and sub-scores (Table 4 and Figure 2).

The proportion of mothers who rated their baby better than average was higher in the intervention group for the overall score difference (78% vs. 40%) (Table 5). The relative probability of rating the own baby better than average was 1.94 (95% CI 1.00–3.79) in the intervention group.

Of the NPI sub-scores, the largest differences between the intervention and non-intervention groups were observed for crying and sleeping [mean difference for crying 1.0 (95% CI 0.6–1.4) and mean difference for sleeping 0.8 (95% CI 0.2–1.3)] (Table 4).

4. Discussion

In this RCT, mothers of preterm infants who received live music therapy in the NICU rated their own infant more favorably on the NPI compared to mothers whose infants did not receive music therapy. The overall NPI scores in the intervention group were more positive compared to the control group, with small to medium effect sizes for both the total NPI II scores and the NPI score difference.

Although music therapy in the NICU is aimed primarily at preterm infants, a growing evidence suggests beneficial effects not only on the infants' well-being but also on their parents (Palisin, 1981; Loewy et al., 2013; Bieleninik et al., 2016; Kobus et al., 2021a, 2022a,c; Menke et al., 2021). While our previous investigations on music therapy with preterm infants have focused on directly measuring parental well-being or assessing the perception of the music therapy intervention (Kobus et al., 2021b, 2022c), this study marks the first attempt to evaluate the impact of music therapy on mothers' perception of their own infant in the NICU. Our findings indicate that the mothers' expectations of an average baby did not differ between the intervention and control group. However, there was a more positive perception of their own infant in the intervention group. Hence, it appears that while expectation remained unaffected, the perception of their own infant was positively influenced by the music therapy intervention.

It is well-acknowledged that a mother's expectations can exert influence on an infant's behavior and development (Broussard and Hartner, 1970; Van den Akker et al., 2022). Notably, maternal

TABLE 1 Clinical characteristics of the included patients in the intervention and the control group.

	Intervention group (<i>n</i> = 18)	Control group (<i>n</i> = 15)
Male, <i>n</i> (%)	8 (44%)	12 (80%)
GA (weeks), mean $\pm$ SD (range)	29 + 1 $\pm$ 2.4 (23 + 6–31 + 5)	28 + 5 $\pm$ 2.5 (22 + 6–31 + 5)
Birth weight (g), mean $\pm$ SD (range)	1,273 $\pm$ 390 (590–1790)	1,094 $\pm$ 368 (545–1,800)
Birth weight < 10th Percentile, <i>n</i> (%)	0 (0%)	3 (20%)
Body length at birth (cm), mean $\pm$ SD (range)	37.7 $\pm$ 4.4 (30.0–45.0)	36.6 $\pm$ 4.9 (29.0–46.0)
Head circumference at birth (cm), mean $\pm$ SD (range)	26.8 $\pm$ 2.9 (21.0–30.5)	26.1 $\pm$ 2.6 (21.0–31.5)
Apgar score at 10 min, median (IQR)	9 (8–9)	9 (7–9)
Parenteral nutrition (days), median (IQR)	9 (7–10)	10 (7–15)
Early onset sepsis, <i>n</i> (%)	2 (11%)	2 (13%)
Late onset sepsis, <i>n</i> (%)	4 (22%)	5 (33%)
Corrected GA at discharge (weeks), mean $\pm$ SD (range)	38 + 1 $\pm$ 2.7 (34 + 3–42.3)	40 + 2 $\pm$ 2.6 (35 + 1–45 + 1)
Weight at discharge (g), mean $\pm$ SD (range)	2,758 $\pm$ 512 (2,085–3,780)	3,419 $\pm$ 827 (2,400–5,290)
Body length at discharge (cm), mean $\pm$ SD (range)	47.5 $\pm$ 3.0 (42.3–53.0)	49.8 $\pm$ 3.7 (43.0–56.0)
Head circumference at discharge (cm), mean $\pm$ SD (range)	32.7 $\pm$ 1.7 (30.0–35.5)	35.0 $\pm$ 2.4 (31.0–38.5)
Respiratory support at discharge, <i>n</i> (%)	0 (0%)	0 (0%)
Nasogastral tube at discharge, <i>n</i> (%)	1 (6%)	1 (7%)

GA, gestational age; SD, standard deviation; IQR, interquartile range; cm, centimeter; g, gram.

TABLE 2 Sociodemographic characteristics of the mothers in the intervention group and the control group.

	Intervention group	Control group
Mothers, <i>n</i> (%)	18 (55%)	15 (45%)
Age at birth (years), mean $\pm$ SD (range)	34.1 $\pm$ 4.6 (25.0–40.0)	29.6 $\pm$ 4.2 (20.0–36.0)
Gravida, mean $\pm$ SD (range)	2.9 $\pm$ 2.2 (1.0–8.0)	2.6 $\pm$ 2.0 (1.0–8.0)
Primigravida, <i>n</i> (%)	8 (44%)	5 (33%)
Multigravida, <i>n</i> (%)	10 (56%)	10 (67%)
Number of current child, mean $\pm$ SD (range)	2.4 $\pm$ 1.7 (1.0–6.0)	2.3 $\pm$ 1.9 (1.0–8.0)
Birth mode		
Primary cesarean section, <i>n</i> (%)	9 (50%)	7 (47%)
Secondary cesarean section, <i>n</i> (%)	2 (11%)	1 (7%)
Emergency cesarean section, <i>n</i> (%)	3 (17%)	4 (27%)
Spontaneous, <i>n</i> (%)	4 (22%)	3 (20%)

expectations of their unborn child's temperament appear to extend into postnatal reality, shaping early interactions between the mothers and their child that can further influence the child's temperament development (Van den Akker et al., 2022). A positive mother-infant perception may foster the development of a more stable relationship between mother and infant (Jacobsen et al., 2014). The core concept underlying family-centered music therapy is to improve the emotional interaction between the parents and infant (Jacobsen et al., 2014). This effect has been shown in related fields in the context of music therapy and emotional interaction between parents and their child: In older children with autism spectrum disorders, music therapy improved mothers' confidence to engage with their child and new understanding

of the child's interests and strengths (James et al., 2015; Thompson, 2017). Family-centered music therapy offers parents a novel perception of their child by experiencing them in new ways during music therapy (Annesley et al., 2020). Furthermore, music therapy encourages parents to adopt a more playful and engaged interaction with their children (Kaenampornpan, 2015). Parents link these changes to feeling a closer connection to their child, resulting in an overall improvement in the quality of their relationship (Kobus et al., 2021b). Interestingly, the results of our study align with these previous findings, even though the music intervention itself did not include active parental engagement (Kobus et al., 2021b, 2023). Consequently, it remains uncertain whether the modulation of maternal perception

TABLE 3 Crude and adjusted mean NPI scores and score differences in the intervention and control group at the infants' discharge from hospital.

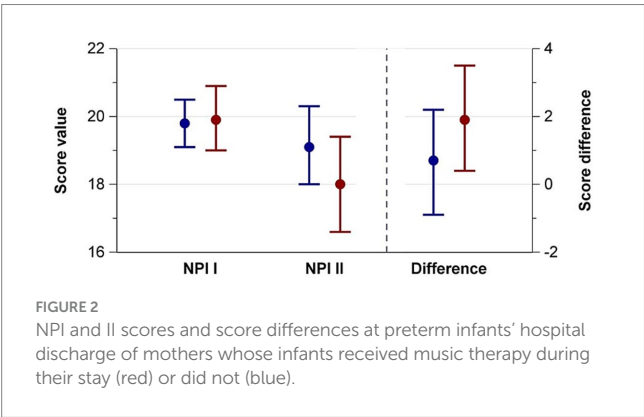
	Mean (95% CI)		Effect size*	Adjusted mean (95% CI)	
	Intervention group	Control group		Intervention group	Control group
NPI I score (average babies)	19.9 (19.0–20.9)	19.8 (19.1–20.5)	0.04	–	–
NPI II score (own baby)	18.0 (16.6–19.4)	19.1 (18.0–20.3)	0.30	17.7 (15.7–19.7)	19.2 (17.0–21.4)
NPI score difference	1.9 (0.4–3.5)	0.7 (–0.9–2.2)	0.27	1.9 (–0.1–3.9)	0.4 (–1.8–2.6)

CI, confidence interval. *Cohen's d between intervention and control group.

TABLE 4 Sub-scores of the NPI I and II scores by intervention.

	Intervention group		Control group		Difference between average and own baby	
	Average babies	Own baby	Average babies	Own baby	Intervention group	Control group
Crying	3.4 (3.2–3.7)	2.4 (2.0–2.9)	3.5 (3.2–3.9)	2.9 (2.5–3.3)	1.0 (0.6–1.4)	0.7 (0.1–1.2)
Feeding	3.1 (2.7–3.4)	3.3 (2.9–3.8)	2.7 (2.4–3.1)	3.0 (2.4–3.6)	–0.3 (–0.7–0.2)	–0.3 (–0.9–0.3)
Spitting or vomiting	3.5 (3.1–3.9)	3.0 (2.5–3.5)	3.3 (3.1–3.6)	2.9 (2.4–3.3)	0.5 (–0.1–1.1)	0.5 (0.0–0.9)
Sleeping	3.0 (2.6–3.4)	2.2 (1.8–2.6)	3.1 (2.8–3.4)	3.3 (2.9–3.7)	0.8 (0.2–1.3)	–0.1 (–0.6–0.4)
Eliminating	3.5 (3.0–4.0)	3.7 (3.3–4.0)	3.5 (3.1–3.8)	3.7 (3.2–4.2)	–0.2 (–0.7–0.4)	–0.3 (–1.0–0.5)
Predictability	3.2 (2.7–3.6)	3.1 (2.4–3.7)	3.3 (3.0–3.7)	3.5 (3.0–4.0)	0.1 (–0.5–0.8)	–0.1 (–0.8–0.5)

All data represent mean and 95 confidence intervals.



was directly influenced by the music intervention or if it occurred indirectly via receiving a “special” intervention.

The primary limitations of this study include a small sample size and a one-dimensional quantitative assessment of mother-infant relationship using the NPI questionnaire, without longitudinal NPI assessment. Qualitative assessment of mother-infant perceptions might uncover additional dimensions of changes to the mother-infant interaction. Another relevant constraint is that mothers were only present in 37% of the sessions. As a result, it is possible that the influence on maternal perception may be solely attributed to the music therapy intervention itself but rather to the awareness that the infant was receiving a “special” intervention. Since the primary focus

of the main RCT was not designed to address this question, we can only conclude that there was a difference in maternal perception between music and no music therapy, without determining whether a different form of music therapy intervention, such as one involving active maternal engagement, would have yielded more pronounced effects on maternal perception.

In summary, this study adds evidence to the existing literature, supporting the idea that music therapy offers parents opportunities to perceive themselves and their infants or children in novel ways (Allgood, 2005; Lindenfesler et al., 2012; Thompson, 2017; Kobus et al., 2021b). Further research is needed to explore moderating impacts of music therapy on family dynamics and parent-child relationships. Decision makers within the (German) healthcare system should become more aware of the comprehensive effects that music therapy exerts not only on the patients themselves but on the entire family unit. The growing evidence of its positive psychological effects should prompt the inclusion of music therapy as a standard treatment covered by the health system, rather than requiring private funding in order to provide this family-nurturing intervention.

5. Conclusion

In this study, individually delivered live music therapy for preterm infants at NICU positively impacted the mother-infant relationship. This findings contributes to the growing body of evidence demonstrating that music therapy can have nurturing psychological

TABLE 5 Comparison of NPI direction between mothers of preterm infants with and without music therapy.

	Intervention group (n = 18)	Control group (n = 15)
Positive direction (better than average)	14 (78%)	6 (40%)
Negative direction (less than average)	4 (22%)	8 (53%)
No direction (average)	0 (0%)	1 (7%)

effects, not only on patients but also their families, particularly during critical, chronic or life-shortening illness.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving humans were approved by the Ethik-Kommission Universität Duisburg-Essen Robert-Koch-Straße 9-11, 45147 Essen. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

NB, MVD, UF-M, and SK: study design. SK and MD: delivery of music therapy. NB: statistical analyses and figures. SK: drafting of manuscript. NB, BH, MVD, PM, UF-M, and A-KD: critical revision. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Early stress during NICU stay and parent-reported health-related quality of life after extremely preterm birth: an exploratory study with possible targets for early intervention

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Introduction: The association between neonatal intensive care unit (NICU) related stress in preterm infants and their health-related quality of life (HRQoL) in the first year following preterm birth remains unexplored. Understanding this association is crucial for enhancing preventive and supportive measures for infants and parents within and beyond the NICU.

Methods: From a single center observational cohort study, we included infants with gestational ages below 30 weeks and/or birth weights under 1,000 grams. HRQoL was quantified using the Infant Quality of Life Instrument (IQI) at 3-, 6-, 9- and 12-months corrected age, covering seven domains. NICU stress was quantified using the Neonatal Infant Stressor Scale (NISS) for the first week of life. We performed Spearman's correlation analyses to test this association.

Results: Of the 45 included infants, the IQI was completed for 27 (60%) at 3, 15 (33%) at 6, 14 (31%) at 9 and 15 (33%) at 12 months. The HRQoL sum scores were related to neonatal stress at 9 and 12 months ($p = 0.643$ and 0.591 , $p = 0.013$ and $p = 0.019$, respectively) but not at 3 and 6 months ($p = -0.001$ and -0.077 respectively, $p > 0.05$). Higher NICU stress tended to be associated with more respiratory and mood problems throughout the first year.

Discussion: From a parental perspective on infant HRQoL, extremely preterm infants with higher stress exposure show more problems in the second half-year of life, mainly breathing and possibly mood-related problems. This knowledge may help improve our neonatal care, both during NICU stay and in follow-up clinics, by implementing targeted interventions.

KEYWORDS

health-related quality of life, parental perspectives, extremely preterm infants, neonatal intensive care unit, NICU-related stress

Introduction

Prematurity is a global health concern that poses a significant challenge. Approximately every one in ten children born worldwide is born preterm, i.e., before 37 weeks of gestation (1, 2). While medical advancements have improved the survival rates of preterm infants, the long-term adverse effects on health and neurodevelopment remain (3–7). For example, these infants are at higher risk of cognitive and motor delays, as well as behavioral and emotional problems. A part of these adverse effects is attributed to exposure to neonatal stress (8), which refers to physiological and psychological stress experiences undergone by preterm neonates during their period in the Neonatal Intensive Care Unit (NICU).

While the developmental consequences of preterm birth have been well established, less is known about health-related quality of life (HRQoL) during the first year of life. Amongst HRQoL domains are regulatory problems, i.e., encompassing feeding, sleeping, and crying. Particularly these three domains have been subject of study and estimates are that approximately one in five preterm children have at least a single regulatory problem (9). The prevalence of combined regulatory problems in crying and sleeping among preterm children is debated, while for feeding a consistently higher prevalence is reported (9). Regulatory problems have consequences in later life, including a higher risk of obesity at pre-school age (10), and childhood attention problems (11). In addition to feeding, sleeping, and crying, parents and experts in the field also consider breathing, stooling, skin, interaction, and mood important domains in the first year after birth (12).

Whether problems in these HRQoL domains are associated with neonatal stress exposure is unknown, but this seems plausible, especially for the regulatory domains (13). Proposed mechanisms include a triggered and exaggerated stress system and a possible impact on parent–child bonding. Understanding the relationship between neonatal stress and HRQoL is crucial for developing more effective preventive and supportive measures for parents and infants both during NICU stay and beyond. Therefore, we aimed to determine the association between early NICU-related stress and outcomes in HRQoL domains during the first year after birth in an exploratory study.

Methods

Setting and participants

We included 45 infants as part of the Stress and Outcomes in NICU Graduates (STRONG) study, a single center observational cohort study from the Netherlands. All infants were born between September 2019 and December 2020 and had a gestational age of less than 30 weeks and/or a birth weight below 1,000 grams. All parents of eligible infants were approached shortly after birth and provided written informed consent before inclusion in the study. The study was approved by the Medical Ethical Review Board of the University Medical Center Groningen (METc 2019/128) and this study was also registered online (ISRCTN62164166).

Quantification of neonatal stress

We prospectively collected all stress-related procedures using the Neonatal Infant Stressor Scale (NISS) from the electronic patient files. This scale is developed by Newham and colleagues to reflect cumulative stress exposure for neonates (14). It includes stressful stimuli in different gradations, i.e., ranging from a little stressful (scored 2 points) to extremely stressful (scored 5 points), and both acute and chronic items are included. Examples of acute stressors include for example suctioning of nose and mouth, lumbar punctions, insertion of intravenous access lines or other skin-breaking procedures. Examples of chronic stressors include for example receiving continuous positive airway pressure (CPAP) or phototherapy or suffering from an infection. All these stressors are summed for a single day to reflect cumulative NICU related stress for that day. We summed each day in the first week of life to form a seven-day cumulative score. A previous study from this cohort showed that most stress occurs in this first week of life (15).

Quantification of HRQoL

Parents were asked to complete the Infant Quality of Life Instrument (IQI) at 3, 6, 9 and 12 months corrected age. All parents were asked to complete the IQI as part of the cohort study and received e-mail reminders at the indicated time-points. The IQI is a digital application that covers the seven domains of HRQoL deemed essential by parents and experts in the field of pediatrics (12). These domains are feeding, breathing, stooling, sleeping, skin, interaction, and mood. On a scale of one to four, parents were asked to rate whether there are problems on a certain domain and how severe these problems are in their opinion. They did not provide qualitative details, e.g., examples, on the reported problems.

Statistical analyses

First, we provide descriptive statistics for the cohort of infants. Then, we describe the amount of reported HRQoL problems. As a third step, we summed HRQoL problems and calculated Spearman's correlation coefficients with neonatal stress exposure. Next, we performed more in-depth testing of each domain separately by classifying each domain into 0, not reported as having a problem, and 1, reported to have a problem. In these groups, we compared NISS scores using boxplots and Mann–Whitney *U*-tests.

Results

In total, 93 infants were eligible to participate in the STRONG study. Of these, 48 did not participate because of missing informed consent due to decease ($n = 6$), language barrier ($n = 2$), or logistical reasons including the COVID-19 research stop ($n = 25$). In total 15

parents declined participation. Of these non-participating infants, some characteristics differed, including being part of a multiple, decrease during NICU stay and associated shorter NICU stay and suffering from necrotizing enterocolitis. The final sample consisted

TABLE 1 Participant characteristics for all infants in the “stress and outcomes in NICU graduates study (STRONG)”.

	Descriptive (N = 45)
Gestational age (weeks)	27 (26–28)
Birth weight (grams)	1,000 (790–1,248)
Male sex	22 (48.9)
Multiple birth	9 (20.0)
Apgar 1 min	5.5 (3.0–7.0)
Apgar 5 min	7.0 (6.0–8.0)
NICU admission for surviving infants (days)	35 (24–49)
Deceased during NICU admission	2 (0.4)
Delivery via caesarean section	23 (51.1)
Antenatal steroids	38 (84.4)
Complete course	23 (51.1)
IVH grade ≥grade 3	6 (13.3)
Mechanical ventilation	30 (66.7)
Days (n = 30)	7.0 (2.8–20.5)
NEC	4 (8.9)
Sepsis	16 (35.6)
Circulatory insufficiency	5 (11.1)
PDA	20 (44.4)

Data are presented as median (25th–75th percentile) or N (%) where appropriate. NICU, neonatal intensive care unit; IVH, intraventricular haemorrhage based on serial cranial ultrasound measurements routinely performed every week; NEC, necrotizing enterocolitis; PDA, hemodynamically significant patent ductus arteriosus determined by cardiac ultrasound. Complete course of antenatal steroids was defined as birth >48 h after the first dose. Presence of intestinal pathologies was based on clinical and radiographic examinations. Sepsis was defined as clinical signs of infection, combined with a positive blood culture, and requiring antibiotic treatment. Circulatory insufficiency was defined as requiring fluid therapy and/or treatment with inotropic agent such as dopamine or dobutamine.

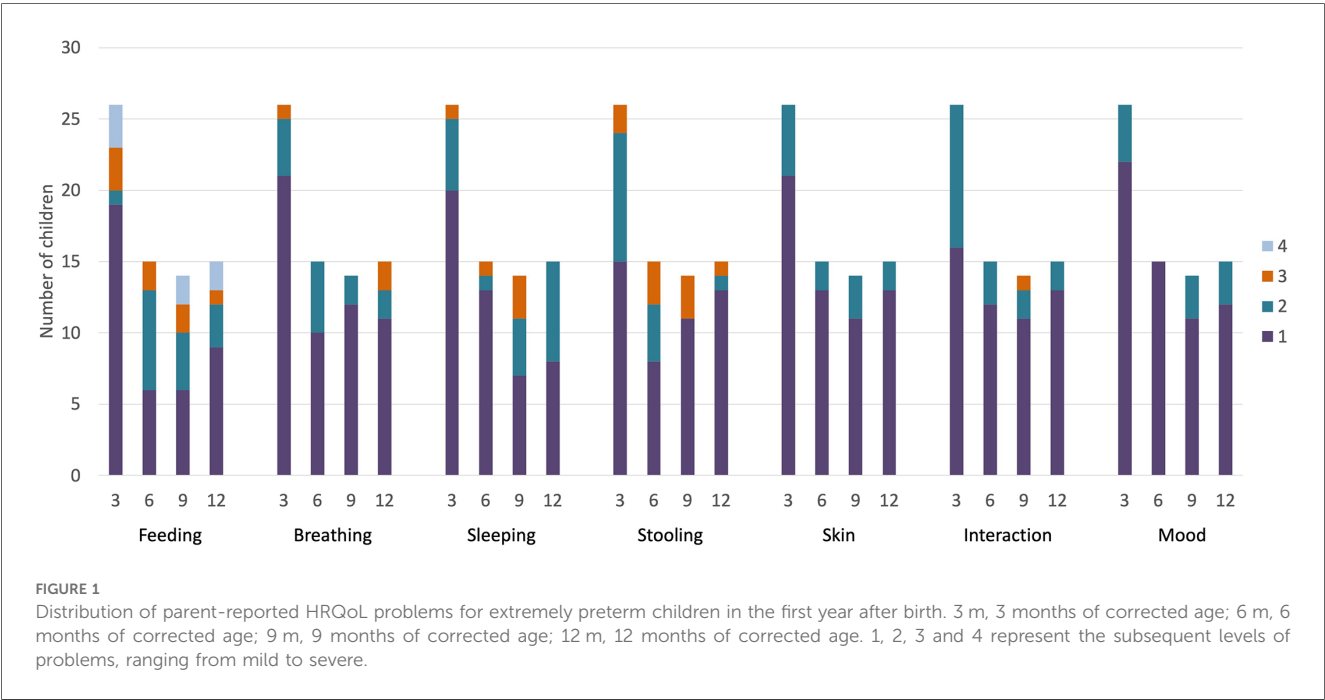
of 45 infants, with a median gestational age of 27 weeks (range 26–28 weeks) and a median birth weight of 1,000 grams (range 790–1,248 grams). All participant characteristics are provided in Table 1.

HRQoL domains

Of the 45 included infants, the IQI was completed for 27 (60%) at 3 months, 15 (33%) at 6 months, 14 (31%) at 9 months and 15 (33%) at 12 months. Parent-reported problems were most common in the feeding, breathing, sleeping, and stooling domains (Figure 1). In the feeding domain, problems were reported to be most severe.

Relationship between neonatal stress exposure and HRQoL

The HRQoL sum scores were not significantly related to neonatal stress exposure at 3 and 6 months of age ($\rho = -0.001$ and -0.077 respectively, $p > 0.05$), whereas at 9 and 12 months of age they were related ($\rho = 0.643$ and 0.591 , $p = 0.013$ and $p = 0.019$, respectively). When performing in depth analyses for groups we did not find an association between neonatal stress and feeding problems (Figure 2A). For breathing, we found tendencies towards higher NICU-stress in children with more respiratory problems in the first half year after birth ($p = 0.085$ at 3 months, $p = 0.057$ at 6 months), while we found significant differences in the second half year after birth ($p = 0.028$ at 9 months and $p = 0.026$ at 12 months; Figure 2B). We also found tendencies towards higher NICU-stress in children with more mood problems in the second half year of life ($p = 0.11$ at 9 months and $p = 0.070$ at 12 months; Figure 2G). For the other domains, we did not identify any significant patterns (shown in Figures 2C–F).



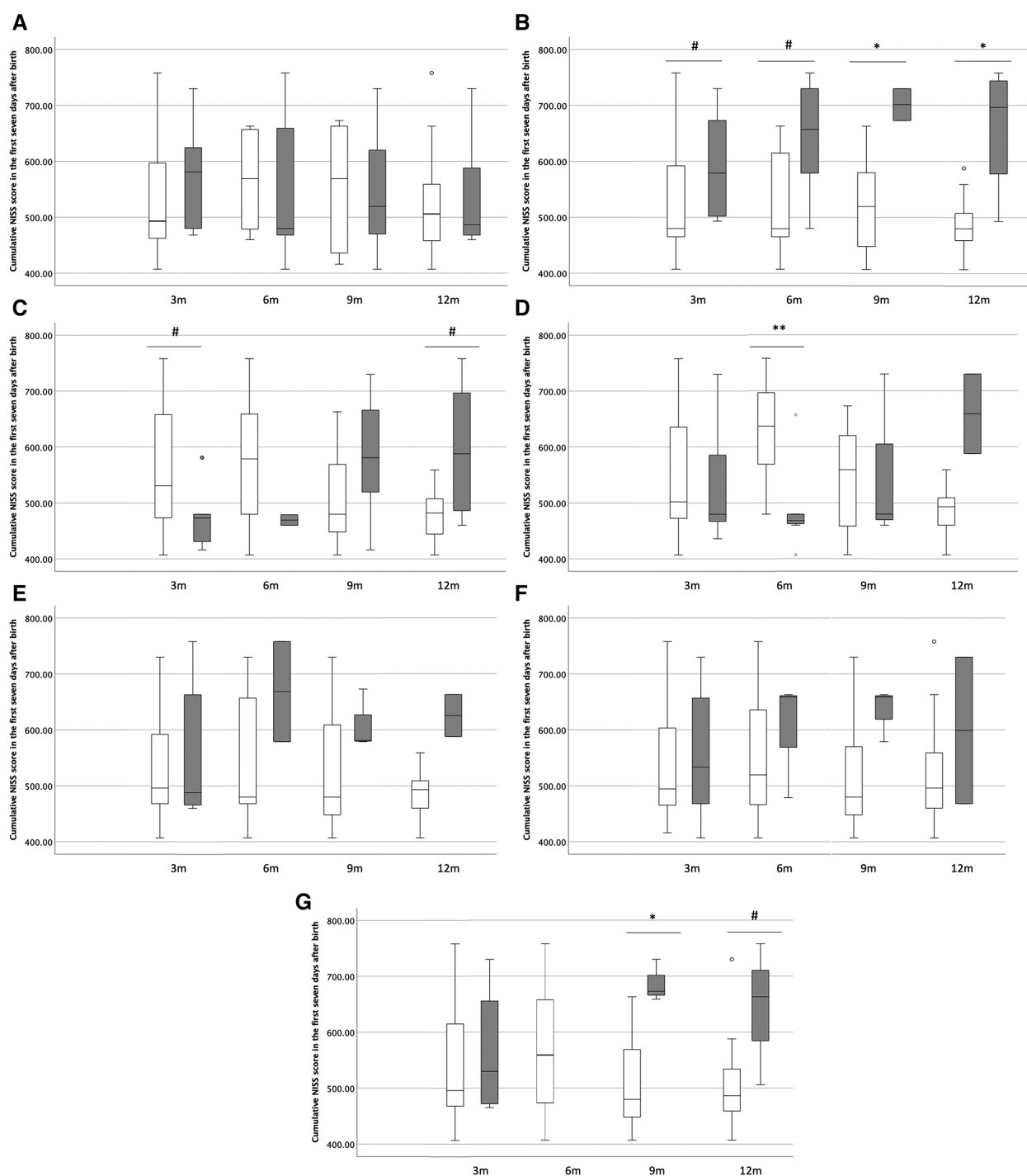


FIGURE 2

In depth analysis of HRQoL domains in the first year of life. (A) Feeding, (B) breathing, (C) sleeping, (D) stooling, (E) skin, (F) interaction, (G) mood. In the box-whisker plots, the boxes represent the distribution of NISS scores of the first seven days after birth (25th to 75th percentile) and the whiskers represent the width of scores. White boxes represent children without parent-reported problems, while grey boxes represent children with parent-reported problems. 3 m, 3 months of corrected age; 6 m, 6 months of corrected age; 9 m, 9 months of corrected age; 12 m, 12 months of corrected age. NISS, Neonatal Infant Stressor Scale. # $p < 0.10$, * $p < 0.05$, ** $p < 0.005$.

Discussion

With this study, we aimed to determine the association between early NICU-related stress and outcomes in HRQoL

domains during the first year after birth. We found that overall neonatal stress exposure during the first seven days after birth are related to cumulative HRQoL problems in the second half-year, but not the first half-year after birth. Additionally, with this

exploratory study, we suggest that early neonatal stress is associated with breathing problems, and possibly with more mood problems as well, but not with feeding or sleeping problems, nor with the other HRQoL domains.

We were surprised by our finding of an association between cumulative HRQoL problems and neonatal stress in the second half-year of life, but not in the first half-year of life. To the best of our knowledge, ours is the first study to explore the relationship between NICU-related stress exposure and HRQoL in the first year after birth. We therefore are unable to compare our results to others. We speculate that the second half-year of life includes a transformation from tiny baby to infant, including transitions in several of these HRQoL domains. This may lead to increased parent-reported problems in children exposed to more NICU-related stress, who may handle such transitions differently than children exposed to less NICU-related stress. A mechanism may be altered brain development, or altered stress system development, which we know to occur after higher NICU-related stress exposure (8).

For the individual domains, we found the most consistent differences in stress exposure for children with and without breathing problems throughout the first year after birth. We propose that this is partly because the NISS score includes respiratory support, including conventional ventilation, but also CPAP or high flow nasal cannula (HFNC) support (14). Children with higher stress exposure may therefore have been exposed to more respiratory support. However, this study only included the first seven days after birth as a source of stress exposure and did not look beyond. An additional explanation may regard the existence of bronchopulmonary dysplasia (BPD) in extremely preterm children, who may indeed experience more respiratory problems later in life (16). A third explanation derived from clinical practice may be that children are attending daycare in the second half-year, even though it is advised to parents of preterm children not to in the first year of life. We propose a combination of these explanations underlying our findings.

Importantly, respiratory support and respiratory problems in the first year of life may be improved by early interventions. While medical advancements have already employed many of these, including for example early caffeine treatment and altered ventilation practices, non-pharmacological interventions that can be continued beyond the NICU should not be overlooked. Music therapy may be a promising non-pharmacological intervention in this respect. While studies on music therapy in the first year of life are scarce, we do know that breathing exercises, singing, and playing wind instruments at school age are associated with improvements in asthma symptoms (17). The Rhythm Breath and Lullaby method that is adopted more and more in NICUs worldwide also includes interventions focused on infant breathing. As we also observed more reported mood problems in the second half-year of life in infants with higher NICU-related stress exposure, music therapy may also have implications for that HRQoL domain.

This study included HRQoL from a parental perspective. We strongly believe that the parental perspective is invaluable for

follow-up care of our most vulnerable patient population. As we know that parents of extremely preterm infants have altered attachment and bonding (18), and may also experience post-traumatic stress during NICU stay and beyond (19), which may affect their perspectives on health problems in their child, integrating parental perspectives of HRQoL is crucial. Besides including the parental perspective, post-traumatic stress during NICU stay and beyond may also affect physiological development of preterm infants and thereby explain our results. Parental resilience and support by other health-care professionals, even in the home setting, may be part of the explanation of our results too. Perhaps interventions are provided in the first months after discharge that are gradually phased out in the second half-year of life, reflecting the associations found in our study. While these explanations are only speculative, they should be subject of future studies, just as parenting styles, that may impact regulatory problems and thus HRQoL as well (13). By including the parental perspective, follow-up clinics and professionals working in neonatal follow-up are given a tool to start the conversation directed towards individual cases.

Strengths and limitations

To our knowledge, this is one of the first studies to take a close look at HRQoL in the first year of life, including neonatal stress as a specific risk factor. As stated before, we consider the parental perspective that is provided in this study as a strength as well. We acknowledge that our study includes a limited sample of extremely preterm infants and that response rates at later timepoints even make the sample smaller. Findings may either be overestimated in the case that parents will respond more promptly if they experience problems, or underestimated in the case that parents experience more space for study participation when they experience little problems. Therefore, results should be interpreted with caution and should be confirmed in larger prospective studies.

Conclusion

From a parental perspective on HRQoL in seven domains during the first year after birth, extremely preterm infants with higher stress exposure show more problems in the second half-year of life, in particular breathing problems and to a lesser degree mood-related problems. This knowledge may help to improve our neonatal care, both during NICU stay and in follow-up clinics, using tailored interventions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Medisch Ethische Toetsingscommissie (METc) University Medical Center Groningen (METc 2019/128). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

ND: Conceptualization, Data curation, Formal Analysis, Investigation, Project administration, Visualization, Writing – original draft. AB: Conceptualization, Methodology, Supervision, Writing – review & editing. KK: Validation, Writing – review & editing. HB: Data curation, Project administration, Validation, Writing – review & editing. SR: Conceptualization, Validation, Writing – review & editing. PK: Conceptualization, Data curation, Investigation, Resources, Software, Validation, Writing – review & editing. MK: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The Infant Quality of Life Instrument as used in this paper was developed by PK, as part of academic/commercial activities.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Euterpe music therapy method for children with cerebral palsy

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Introduction: The main purpose of our study was to evaluate whether involvement in a personalized music therapy program (Euterpe method), could improve the condition of children with cerebral palsy and their parents, compared to a control group. It investigated whether it could positively affect children's sleep quality, temperament and quality of life, quality of family life, and parental stress.

Methods: A prospective single-center experimental study was conducted at "Bambino Gesù" Children's Hospital (Rome, Italy). All subjects involved attended an intensive rehabilitation program in the Neurorehabilitation Unit. In a group of patients ($n = 25$), a music therapy treatment was applied to evaluate the effect before and after the intervention. This group was also compared with a control group ($n = 10$) undergoing a standard protocol without music therapy.

Results: In the experimental group, the analysis shows statistically significant effects in the Disorders of initiating and maintaining sleep ($p = 0.050$) and the Sleep wake transition disorders ($p = 0.026$) factors, and the total score ($p = 0.031$) of Sleep Disturbances Scale for Children; the Positive emotionality scale ($p = 0.013$) of Italian Questionnaires of Temperament (QUIT); the Emotional Functioning ($p = 0.029$), Social Functioning ($p = 0.012$), Worry ($p = 0.032$), Daily Activities ($p = 0.032$), Total Score ($p = 0.039$) and Parent HRQL Summary Score ($p = 0.035$) dimensions of Pediatric Quality of Life for family. While in the control group, only the Attention scale of QUIT ($p = 0.003$) reaches statistical significance.

Discussion: Our study suggests that music therapy with the Euterpe Method has beneficial effects on fundamental aspects of the child's and his parents' lives, such as sleep, emotion control, and quality of family life.

KEYWORDS

music therapy, cerebral palsy, neurorehabilitation, Euterpe method, sleep disturbances, quality of life, parental distress, children

1 Introduction

Cerebral palsy (CP) is a neurodevelopmental condition that begins in early childhood and persists throughout life. It is defined as a group of permanent disorders of the development of movement and posture, causing activity restriction that is attributed to non-progressive lesions occurring in the developing fetal or infant brain. Motor disorders in CP are often accompanied by sensory, perceptual, cognitive, communication, and behavioral disorders, epilepsy, and secondary musculoskeletal difficulties (1). In this context, multisensory stimulation

interventions may improve sensory and motor function (2). A systematic literature review found that visual-perceptual impairment ranged from 40% to 50% in children with CP (3), as also confirmed by Rauchenzauner et al. (4), who found visual-perceptual impairment in 59.5% of them. Novak also reports that 4% of children with CP have severe hearing problems or are deaf (5). Motor learning is frequently impaired by deficits in sensory information processing (6). Both sensory and perceptual disturbances can be directly related to the CP etiology or the result of a child's limited activities, experiences, and learning (7).

The recent review by de Almeida et al. found that muscle spasms, contractures, and reduced ability to change body position at night in children with CP interfere with sleep quality. The studies reviewed highlighted the severity of sleep disorders and report an incidence of the population with CP ranging from 23.4% to 46% (8).

Interventions for children with CP include rehabilitation treatments, medical therapies, and orthopedic surgery (9). Castelli et al. explained that rehabilitation is a complex process aimed at promoting the best possible participation and quality of life for the child and family (10). Moreover, early auditory-tactile-visual-vestibular rehabilitation improved motor and cognitive performance in children with severe brain injury or extreme prematurity, as described by Nelson et al. (11). Holt and Mikati comprehensively reviewed the effects of early rehabilitation to improve the functional development of infants with perinatal brain damage. They concluded that exposure to enriched sensory environments can improve cognitive outcomes and increase brain growth (12).

In addition to conventional rehabilitation, music therapy can help achieve the treatment goals.

The World Federation of Music Therapy, after the absorption of several associations, based on international experiences has defined music therapy as *"the professional use of music and its elements as an intervention in medical, educational, and everyday environments with individuals, groups, families, or communities who seek to optimize their quality of life and improve their physical, social, communicative, emotional, intellectual, and spiritual health and wellbeing. Research, practice, education, and clinical training in music therapy are based on professional standards according to cultural, social, and political contexts"* (13).

Since 1944, when the first-degree course was held at Michigan State College in the United States, music therapy has had a constant and ever-increasing development toward scientific research and clinical therapy. However, it was in the 1990s that the live observation provided by neuroimaging techniques led to the birth of neurological music therapy. Diagnostic imaging techniques have provided research, that studies and correlates brain activity and music, with demonstrations of significant effects on the stimulation of physiologically complex cognitive, affective, and sensorimotor processes (14). These findings are an important therapeutic aid for the treatment of children with CP.

The study of Alves-Pinto et al. investigated music-supported therapies for the rehabilitation of motor disorders. Their findings showed that actively playing a musical instrument can be an effective means of promoting the coordination of hand movements and, more generally, triggering the neuroplastic processes necessary for the development of sensorimotor skills in patients with early brain damage (15). Ghai et al. (16) analyze the effects of rhythmic auditory cueing on gait in people with CP. Their review suggests evidence for applying rhythmic auditory cueing to enhance gait performance and

stability. Motor function in CP people has also been studied by Kantor et al. (17) in correlation with the effects of vibroacoustic therapy. They stated a statistically significant improvement in children's and adult's range of motion. Marrades-Caballero et al. (18), investigating the impact of an optimized music therapy program including active music techniques on the function of children with CP, observed significant improvements in the overall and specific "arm and hand position" as well as "activities." All of these improvements persisted after 4 months. The study by Coppola et al. highlights the reduction of epileptic seizures following the administration of Mozart's sonata for two pianos in D major, K448. The authors did not study the implications of sleep, but parents reported observations of improved sleep and daytime behavior (19).

Since the effect of music therapy has been studied in CP children mainly about motor aspects or training with musical instruments, our study wanted to investigate different critical aspects of the child's life. De Almeida et al. report the need to conduct scientific research to investigate the problem of sleep quality related to quality of life in children with CP and their families (8).

Our study is the first aimed to evaluate whether a personalized music therapy program according to the Euterpe Method (EM), conducted by a certified music therapist, can positively affect the sleep quality, temperament, and quality of life of children with CP, the quality of family life, and parental stress.

2 Materials and methods

2.1 Study design

A prospective, single-center, experimental, study was conducted at the "Bambino Gesù" Children's Hospital (Rome, Italy) between May 2021 and August 2022.

All subjects involved in the study attended an intensive rehabilitation program in the Neurorehabilitation Unit of the Hospital as in-patients. According to the child's needs, the rehabilitation takes place daily, 3 h a day, 6 days a week. It includes physiotherapy, neuromotor rehabilitation, speech therapy, occupational therapy, psychomotor therapy, neuro-visual and communicative rehabilitation.

Enrollment criteria were as follows: age between 0 and 10 years, diagnosis of CP according to Morgan et al. (20), and in-hospital stay between 3 and 4 weeks for intensive rehabilitation. Children with severe hearing problems or deafness were excluded.

We included children with CP younger than 10 years of age because afterward, patients have a higher possibility of presenting with secondary impairments and complications that worsen function or interfere with learning. Pain secondary to musculoskeletal problems is less frequent in children than in adolescents (21). Furthermore, in older children with CP, excessive knee flexion and crouch gait are common (22). Throughout adulthood, a gradual decline in functional ability has been reported across all Gross Motor Functional Classification System levels (GMFCS) (23). Moreover, early life is the period with the highest potential to counteract negative sequelae, given the high plasticity of the young brain (24). We included children with CP because it is the leading cause of chronic disability in pediatric patients (25). Considering that in our department children undergo music therapy three times a week and, according to our experience, it takes about eight sessions to achieve the therapeutic goals. For these

reasons, we have included only patients who have been hospitalized for at least 3 weeks. We used the GMFCS to assess their functional status (26). The GMFCS is a 5-level functional classification that differentiates children and youth with CP according to their current gross motor abilities. Children with GMFCS level I can generally walk without restrictions, while those classified as level V are usually very limited in their ability to move themselves.

Informed consent was provided to the parents of the children who met the inclusion criteria of the study. All parents received and autonomously completed the parent-report questionnaires for assessment at T0 at the time of inclusion in the study.

Following randomization, An EM music therapy treatment was administered to a group of children (experimental group—EG), to assess the effect before and after intervention. The same group was compared with a control group (CG). This latter underwent a rehabilitation program without music therapy.

All children included in the study were hospitalized for intensive rehabilitation and returned home only upon discharge. Therefore, there could be no interference with other music therapy programs carried out at home or with listening to ambient music.

EG and CG parents, whose children had completed the rehabilitation pathway, autonomously filled out the parent-report questionnaires at T1, 3 weeks after T0.

The outcome assessor was a psychologist who was blinded to the assignment of children to one of the two groups (randomization) and the scoring of questionnaires completed by parents. The psychologist was always the same person and did not intervene in the compilation process.

The whole process is summarized in the flowchart (Figure 1).

2.2 Euterpe method's music therapy

The EM is a type of music therapy in which music is associated with sensory stimulation, following specific algorithms and procedures.

Therapy is aimed at the child and requires the involvement and active participation of the parent. The activity is called Sound in Multisensory Stimulation. These are complex sensory and cross-modal stimulations using elaborate sounds and personalized compositions in osmosis with the environment.

In this study, *EM active* music therapy was used, which is the most operative modality of the methodology. It is carried out in a logical consequential succession of “*sound actions*” and therapeutic activities aimed at achieving the clinical goals established by the medical team.

The EM music therapy protocol was designed based on the clinical needs of the intensive neurorehabilitation program. This program is carried out in a minimum hospitalization of 3 weeks, to have at least 8 EM sessions with the child and parent, plus the “*sound anamnesis*” session.

EM active starts with the sound anamnesis called “*personal sound history*,” and the creation of a personalized database consisting of four archives.

The personal sound history is divided into two parts: the first is related to the collection of clinical, sensory, and musical information; the second consists of the recording of the mother's voice.

The archives contain: (A) clinical data, categorizations of the different sounds; (B) videos of the therapy sessions; (C) significant

photos of the therapeutic pathway; (D) cards describing the activities carried out in the different treatment areas.

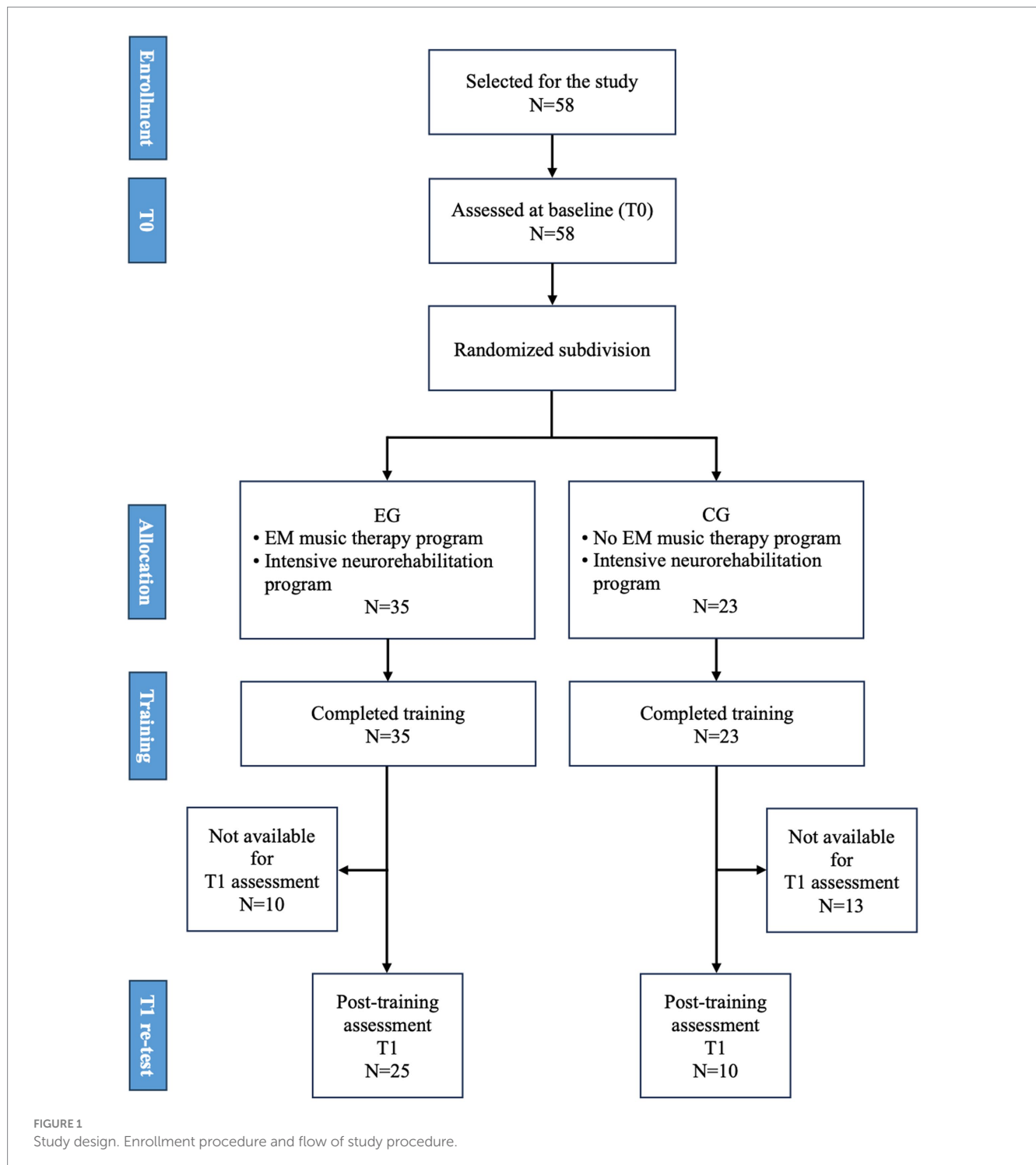
The EM training session follows a specific succession of steps, which begin with the “welcoming phase” of the patient and parent within the multisensory space.

The “*compositional sound interventions*” are a process of steps that begin with the reduction of background noise on the raw track of the mother's voice. As a result, the track is fragmented into audio clips that are named and stored according to categorizations (e.g., prosodies of the child's name, endearments, positive reinforcements, lullabies, songs, etc.). The mother's pre-recorded sound allows us, from the first therapy, to send the audio clips to the different sources of propagation (loudspeakers). In addition, of considerable importance, the pre-recorded sound can be simultaneously superimposed on the speech of the mother addressing her baby. This intervention is mainly conducted in order to motivate and direct the patient toward the sound source and promote mother–child emotional interaction.

The following are the steps in a succession of the “compositional sound interventions” and the aims: (1) the instrumental or vocal live has as its main purpose the observation of the child's reactions; (2) the recorded stimuli are re-proposed, and elaborated adapting them to the psychophysiological condition of the patient, in order to activate and motivate the child to interact with the therapeutic action; (3) the administration of effective clips (e.g., edited child and mother's voices, known music, soundscape, and landscape), is intended to activate visual, motor, and emotional areas; (4) finally, the personalized composition is made with the overlapping of all the clips that are most effective for the therapeutic objectives (see Figure 2).

In support of the effects of this musical procedure, we cite the work of Koelsch. He states that the therapeutic action of music involves brain structures in cognitive, sensorimotor, and emotional processing. In addition, he asserts that music involves sensory processes, attention, memory-related processes, and perception-action mediation (“mirror neuron system” activity). Finally, he hypothesizes that the activation of these processes by music may have beneficial effects on the psychological and physiological health of individuals, although the mechanisms underlying these effects are currently not well understood (27). Similarly, Magee et al. (28) also state that interventions with music are used in rehabilitation to stimulate brain functions involved in movement, cognition, language, emotions, and sensory perceptions.

A fundamental prerogative is that EM music therapy takes place in a personalized and soundproofed multisensory space, named “synesthesia room.” It includes multiple devices: LED projectors, moving heads and strips; a sound diffusion system with mixer and audio interface; several laptops; camcorders; vibrating devices; aroma diffusers; postural instruments; tactile, visual, and olfactory paths; sensors, touch monitors; instruments, and musical objects; and interactions with image projections through augmented reality. In support of EM music therapy, which takes place in a designed space (synesthesia room), we mention Serino's study. In fact, he affirms that “*The brain represents the space to perceive and interact with external stimuli in the environment*” (29). Neuroimaging has shown that multiple representations of space built by the brain are related to specific reference frames. The latter depend on the source of sensory stimulation and nature of the interaction between the individual and environment (30). In this way, Andersen et al. show how multimodal sensory signals, including vision, somatosensation, audition, and



vestibular sensation, converge in the posterior parietal cortex to encode the spatial positions of targets for movement. These signals are combined using a specific mechanism that composes coordinate frames of the various input signals into spatial representations. Within these spatial representations of the posterior parietal cortex are neural activities related to higher cognitive functions, including attention. Thus, there is an intermediate stage between sensory and motor structures that contains an abstract representation of space and the mental operations important for planning movements (31).

Thus, stimulation can be harmonized in a resilient way to the different needs of children and to specific therapeutic objectives previously established by the medical team.

The EM music therapy sessions take place three times a week in the afternoon following the intensive rehabilitation therapies, last 35/40 min each, and are held by a certified professional. In our case, he has two postgraduate Master's degrees in Music Therapy and Autism Spectrum Disorder and three Master's degrees in Orchestral Conducting, Clarinet, and Management in Educational Services.

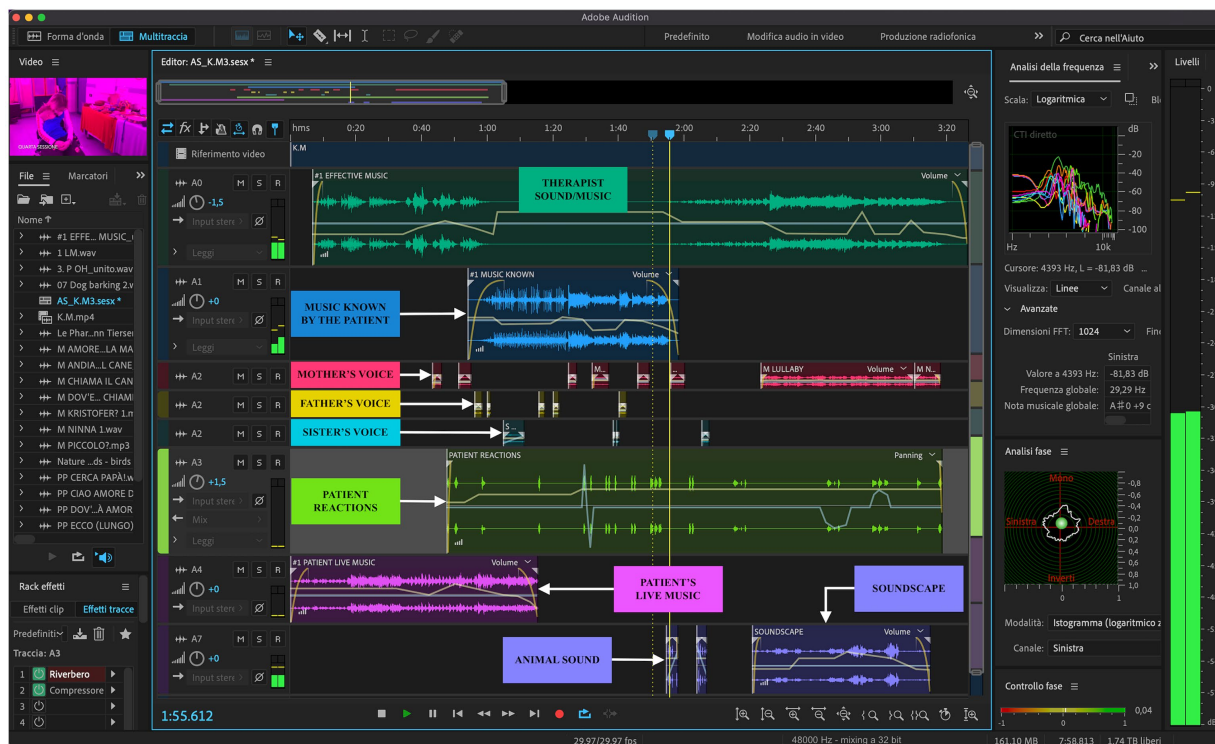


FIGURE 2

An example of a custom composition. The left axis of the image shows the edited video clip of the sessions, the library of audio clips, the effects applied to tracks, and at the bottom are indicated the start, end, and duration of the project; at the top, there is the timeline expressed in decimal time format (mm:ss.ddd); on the right axis there are the Frequency Analysis, the Phase Analysis, the Level Control, and the Level Meter; the bottom shows the Mixer and the effect panels, and finally, the Sample Type in the status bar indicates the 48,000 Hz sample rate, the 32-bit depth, and the buffer size of 1,024.

The objectives of these therapies are: to improve the child's quality of sleep, temperament, and ability to interact with the environment, the relationship between parents and children, and to support mothers' psychological stress. In addition, they are aimed at enhancing the quality of life of both.

2.3 Participants

From a large cohort, we selected 58 children according to the inclusion criteria. They were divided into 2 groups according to randomization, 35 in the EG and 23 in the CG.

Thirty-five children with CP (22 males and 13 females) were selected and underwent music therapy. Twenty-five children (15 males and 10 females) completed the assessment both at T0 and T1 and were included in the EG.

Twenty-three children with CP (11 males and 12 females) of the same age and clinical features of EG were enrolled. They did not attend music sessions but rehabilitative treatments analogous to the children of the EG. Ten children with CP (4 males and 6 females) completed T0 and T1 assessments and were included in the CG.

This study was performed following the Declaration of Helsinki, and informed consent was provided to parents.

For an overview of group characteristics and test statistics, see Figure 1 and Table 1.

2.4 Measures

All children's parents involved in the study (EG and CG) autonomously completed five parent-report questionnaires:

- The Sleep Disturbance Scale for Children (SDSC) (32) is a parent questionnaire used to investigate the quality of sleep among children. In our analysis we use total score and scores obtained in each subscale (DIMS, disorders of initiating and maintaining sleep; SBD, sleep breathing disorders; DA, disorders of arousal/nightmares; SWTD, sleep-wake transition disorders; DOES, disorders of excessive somnolence; SHY, sleep hyperhidrosis).
- The use of Italian Questionnaires of Temperament (QUIT) (33) highlights the child's behavior in interaction with others, when playing and concerning news. QUIT analyzes several domains: social orientation, inhibition to novelty, motor activity, positive emotionality, negative emotionality, and attention. According to the test authors, individual behavioral reactivity to environmental stimuli (as. emotional, attentional, and motor activity) and self-regulation in childhood represent the fundamental components of temperament. The way temperament is expressed is influenced by the environment and life experience (34).
- To investigate the health-related quality of life of children and mothers, we administered the Pediatric Quality of Life. According to age ranges, we dispensed the parent-report questionnaire for infants (PEDSQL-C) (35), toddlers, and

TABLE 1 Descriptive characteristics of the two groups.

		EG (n = 25)	CG (n = 10)	P
Children's variables	Age in groups (years)			0.081 ^a
	0–5	21 (84.0)	5 (50.0)	
	>5	4 (16.0)	5 (50.0)	
	Gender, N (%),			
	Male	15 (40.0)	4 (40.0)	0.454 ^a
	Female	10 (60.0)	6 (60.0)	
	GMFCS, m ± SD	4.0 ± 1.0	3.4 ± 1.4	0.190 ^b
	EM Sessions*, m ± SD	7.5 ± 2.5	-	-

^aResult of a Fisher exact test. ^bResult of a two-sample *t*-test. *The cell is empty because the CG has not carried out the EM music therapy program.

children (PEDSQL-C) (36), and finally the family impact module (PEDSQL-F) (37). In our analysis, we considered all dimensions scores, total scores, and summary scores obtained in different modules. The Parent Report for Infants (used for children ages 1–24 months) comprises 5 dimensions: Physical Functioning (PF), Physical Symptoms (PS), Emotional Functioning (EF), Social Functioning (SF), and Cognitive Functioning (CF). The Parent Report for Toddlers (used for children ages 2–4) and the Parent Report for Children comprise 4 dimensions: Physical Functioning (PF), Emotional Functioning (EF), Social Functioning (SF), and Cognitive Functioning (CF). Parent Report modules for Infants, Toddlers, and Children provide, in addition to scores in individual domains, the Total Score (TOT – sum of all items) and two Summary Scores: Psychosocial Health (PsyHSS) and Physical Health (PhyHSS). The Family Impact Module comprises 8 dimensions: Physical Functioning (PF), Emotional Functioning (EF), Social Functioning (SF), Cognitive Functioning (CF), Communication (Com), Worry (W), Daily Activities (DA), and Family Relationships (FR). In addition to scores in individual domains, this module also provides the Total Score (TOT – sum of all items) and two Summary Scores: Parent HRQL and Family Functioning (FFSS).

- The Parenting Stress Index-Short Form (PSI-SF) (38) was used to investigate parenting stress. In our analysis, we include the total score and its sub-scores (PD, parental distress; PDCI, parent–child dysfunctional interaction; DC, difficult child; DR, defensive responding).

2.5 Statistical analysis

All statistical analyses were performed using STATA, Statistical Software: Release 17 (StataCorp LP, College Station, TX). The Shapiro–Wilk test was used to assess the normality of the data. Categorical variables were summarized by absolute frequencies and percentages, and continuous variables by mean and standard deviation SD.

To determine statistical differences for all scores between baseline (T0) and post-music therapy (T1) the T-test for matched data was used for continuous variables. Furthermore, scores between subjects in the EG and CG were compared at baseline and after music therapy with T-test for independent samples, and categorical variables were compared with Chi-square or Fisher exact test. The statistical significance was set at *p* < 0.05.

3 Results

3.1 Sample’s descriptive characteristics

The baseline comparison of both groups shows the same structural characteristics, i.e., without statistically significant differences.

Gender was analyzed with the Fisher exact test. The sample shows no statistically significant differences (*p* = 0.454).

Even in terms of the assessment of functional status carried out by GMFCS, the difference analyzed with a two-sample *t*-test is not statistically significant (*p* = 0.190).

Age analysis was performed using the Fisher exact test. Also concerning age classifications, the two groups do not differ at baseline (*p* = 0.081).

Thus, EG and CG were homogeneous in the distribution by gender, age, and GMFCS.

3.2 Results of the experimental group

There are statistically significant improvements compared to pre- and post-EM music therapy treatment (Table 2).

The analysis of the SDSC shows statistically significant effects in the DIMS factor (*p* = 0.050), the SWTD factor (*p* = 0.026), and the SDSC total score (*p* = 0.031). Other factors (DA, DOES, and SHY) improved but not significantly, while the SBD factor mean remained unchanged *M* ± *SD* (T0) 4.4 ± 2.4; *M* ± *SD* (T1) 4.4 ± 2.4.

Referring to QUIT, the positive emotionality scale (*p* = 0.013) shows a statistically significant score, while the other scales (inhibition to novelty and negative emotionality) show improvements that, however, are not significant. The social orientation, motor activity, and attention scales also present a result that does not improve.

The PEDSQL-F has a general improvement (PF, CF, Comm, and FFSS), specifically in the EF (*p* = 0.029), SF (*p* = 0.012), W (*p* = 0.032), DA (*p* = 0.032), TOT (*p* = 0.039) and HRQL (*p* = 0.035) dimensions. On the other hand, the value of FR does not improve statistically.

3.3 Results of the control group

The statistical analysis between T0 and T1 of CG is shown in Table 3.

TABLE 2 Scores of the experimental group (results are reported as mean $\pm$ standard deviation).

		T0	T1	P
Sleep Disturbances Scale for Children (SDSC)	Disorders of initiating and maintaining sleep (DIMS)	14.6 $\pm$ 7.1	13.4 $\pm$ 6.1	0.050
	Sleep breathing disorders (SBD)	4.4 $\pm$ 2.4	4.4 $\pm$ 2.4	1.000
	Disorders of arousal (DA)	3.1 $\pm$ 1.6	2.9 $\pm$ 1.0	0.519
	Sleep wake transition disorders (SWTD)	9.6 $\pm$ 3.3	8.0 $\pm$ 2.9	0.026
	Disorders of excessive somnolence (DOES)	7.1 $\pm$ 5.6	5.6 $\pm$ 1.9	0.195
	Sleep hyperhidrosis (SHY)	3.5 $\pm$ 2.4	3.4 $\pm$ 1.8	0.722
	Sleep Disturbance Scale for Children (SDSC) total score	42.4 $\pm$ 14.5	37.7 $\pm$ 12.7	0.031
Italian Questionnaires of Temperament (QUIT)	Social orientation	3.8 $\pm$ 1.3	3.7 $\pm$ 1.2	0.693
	Inhibition to novelty	3.4 $\pm$ 0.9	3.1 $\pm$ 1.2	0.195
	Motor activity	3.3 $\pm$ 0.9	3.3 $\pm$ 0.8	0.950
	Positive emotionality	4.1 $\pm$ 1.4	4.4 $\pm$ 1.2	0.013
	Negative emotionality	2.7 $\pm$ 1.0	2.4 $\pm$ 0.8	0.076
	Attention	3.8 $\pm$ 0.9	3.8 $\pm$ 0.9	0.932
Pediatric Quality of Life 2.0 Family Impact Module (PEDSQL-F)	Physical Functioning (PF)	58.0 $\pm$ 20.2	61.2 $\pm$ 20.8	0.179
	Emotional Functioning (EF)	61.6 $\pm$ 26.4	69.6 $\pm$ 22.6	0.029
	Social Functioning (SF)	61.5 $\pm$ 25.4	68.3 $\pm$ 26.4	0.012
	Cognitive Functioning (CF)	72.8 $\pm$ 21.3	73.6 $\pm$ 18.2	0.730
	Communication (Com)	72.9 $\pm$ 20.1	73.0 $\pm$ 21.6	0.966
	Worry (W)	45.2 $\pm$ 24.6	52.4 $\pm$ 21.5	0.032
	Daily Activities (DA)	39.3 $\pm$ 26.3	46.0 $\pm$ 24.7	0.032
	Family Relationships (FR)	78.2 $\pm$ 22.5	77.8 $\pm$ 23.5	0.877
	Total Score (TOT)	61.5 $\pm$ 18.6	65.5 $\pm$ 17.9	0.039
	Parent HRQL Summary Score (HRQL)	63.1 $\pm$ 19.6	67.5 $\pm$ 19.2	0.035
	Family Functioning Summary Score (FFSS)	63.6 $\pm$ 21.0	65.9 $\pm$ 22.2	0.247
	Physical Functioning (PF)	41.6 $\pm$ 22.8	46.7 $\pm$ 24.7	0.297
	Physical Symptoms (PS)	59.2 $\pm$ 15.9	62.8 $\pm$ 16.8	0.325
Pediatric Quality of Life (PEDSQL-C)	Emotional Functioning (EF)	67.0 $\pm$ 18.1	71.7 $\pm$ 23.9	0.155
	Social Functioning (SF)	55.1 $\pm$ 27.3	60.5 $\pm$ 27.3	0.291
	Cognitive Functioning (CF)	46.5 $\pm$ 37.8	32.5 $\pm$ 37.2	0.283
	School Functioning (SchF)	52.8 $\pm$ 21.5	56.9 $\pm$ 18.6	0.456
	Psychosocial Health Summary Scale (PsyHSS)	59.6 $\pm$ 19.0	62.5 $\pm$ 20.8	0.329
	Physical Health Summary Scale (PhyHSS)	42.9 $\pm$ 21.8	48.6 $\pm$ 25.0	0.187
	Total Score (TOT)	52.6 $\pm$ 16.7	56.7 $\pm$ 18.5	0.135
	Parenting Stress Index-Short Form (PSI-SF)	56.2 $\pm$ 28.2	55.4 $\pm$ 31.5	0.857
Parenting Stress Index-Short Form (PSI-SF)	Parent-Child Dysfunctional Interaction (PCDI)	63.4 $\pm$ 22.0	60.2 $\pm$ 23.6	0.466
	Difficult Child (DC)	53.8 $\pm$ 34.7	54.0 $\pm$ 32.9	0.961
	Defensive Responding (DR)	49.2 $\pm$ 30.2	47.4 $\pm$ 30.1	0.633
	Parenting Stress Index-Short Form (PSI-SF) total score	58.6 $\pm$ 30.2	57.6 $\pm$ 29.4	0.833

Statistically significant values are formatted in bold.

We observe an improvement in the trend in several variables but it does not reach statistical significance except for the attention scale of the QUIT ($p = 0.003$).

The following scales do not show statistically significant effects: PCDI of the PSI; social orientation, inhibition to novelty, and positive

emotionality of the QUIT; CF, DA, and FFSS of the PEDSQL-F; EF of the PEDSQL-C.

Moreover, the trend is unchanged in the FR dimension of the PEDSQL-F, the mean remains the same value while the standard deviation has an irrelevant change $M \pm SD$ (T0) 82.0 ± 17.2 ; $M \pm SD$ (T1) 82.0 ± 17.4 .

TABLE 3 Scores of the control group (results are reported as mean $\pm$ standard deviation).

		T0	T1	P
Sleep Disturbances Scale for Children (SDSC)	Disorders of initiating and maintaining sleep (DIMS)	12.7 $\pm$ 4.1	12.3 $\pm$ 3.1	0.626
	Sleep breathing disorders (SBD)	6.1 $\pm$ 7.4	3.9 $\pm$ 1.0	0.346
	Disorders of arousal (DA)	4.0 $\pm$ 2.2	3.7 $\pm$ 1.3	0.468
	Sleep wake transition disorders (SWTD)	10.4 $\pm$ 4.7	9.4 $\pm$ 2.3	0.497
	Disorders of excessive somnolence (DOES)	5.2 $\pm$ 1.4	5.0 $\pm$ 1.3	0.443
	Sleep hyperhidrosis (SHY)	2.5 $\pm$ 1.1	2.4 $\pm$ 1.0	0.847
	Sleep Disturbance Scale for Children (SDSC) total score	40.9 $\pm$ 11.3	36.7 $\pm$ 7.4	0.095
Italian Questionnaires of Temperament (QUIT)	Social orientation	4.4 $\pm$ 1.1	4.2 $\pm$ 1.1	0.643
	Inhibition to novelty	2.3 $\pm$ 0.4	2.5 $\pm$ 0.8	0.238
	Motor activity	3.0 $\pm$ 1.1	2.9 $\pm$ 1.0	0.493
	Positive emotionality	5.2 $\pm$ 0.6	4.9 $\pm$ 0.8	0.325
	Negative emotionality	2.5 $\pm$ 0.6	2.2 $\pm$ 0.7	0.200
	Attention	4.0 $\pm$ 1.0	4.4 $\pm$ 1.0	0.003
Pediatric Quality of Life 2.0 Family Impact Module (PEDSQL-F)	Physical Functioning (PF)	70.4 $\pm$ 14.1	80.4 $\pm$ 11.8	0.057
	Emotional Functioning (EF)	71.5 $\pm$ 21.4	80.0 $\pm$ 20.3	0.090
	Social Functioning (SF)	73.8 $\pm$ 25.5	80.0 $\pm$ 18.6	0.117
	Cognitive Functioning (CF)	82.5 $\pm$ 18.4	78.0 $\pm$ 24.3	0.171
	Communication (Com)	76.7 $\pm$ 25.7	85.8 $\pm$ 18.4	0.066
	Worry (W)	52.5 $\pm$ 25.7	57.5 $\pm$ 28.2	0.252
	Daily Activities (DA)	61.7 $\pm$ 24.3	60.0 $\pm$ 21.8	0.509
	Family Relationships (FR)	82.0 $\pm$ 17.2	82.0 $\pm$ 17.4	1.000
	Total Score (TOT)	71.5 $\pm$ 17.7	75.8 $\pm$ 15.6	0.138
	Parent HRQL Summary Score (HRQL)	74.4 $\pm$ 17.1	79.6 $\pm$ 14.8	0.119
	Family Functioning Summary Score (FFSS)	74.4 $\pm$ 17.1	73.8 $\pm$ 15.0	0.825
	Physical Functioning (PF)	44.4 $\pm$ 28.1	46.6 $\pm$ 30.6	0.382
	Physical Symptoms (PS)*	-	-	-
Pediatric Quality of Life (PEDSQL-C)	Emotional Functioning (EF)	78.0 $\pm$ 8.6	76.0 $\pm$ 13.3	0.606
	Social Functioning (SF)	63.5 $\pm$ 16.0	68.0 $\pm$ 19.9	0.378
	Cognitive Functioning (CF)*	-	-	-
	School Functioning (SchF)	67.7 $\pm$ 20.3	72.8 $\pm$ 22.1	0.139
	Psychosocial Health Summary Scale (PsyHSS)	70.3 $\pm$ 11.1	72.4 $\pm$ 16.1	0.526
	Physical Health Summary Scale (PhyHSS)	44.4 $\pm$ 28.1	46.6 $\pm$ 30.6	0.382
	Total Score (TOT)	61.1 $\pm$ 15.4	63.2 $\pm$ 19.8	0.449
	Parenting Stress Index-Short Form (PSI-SF)	46.6 $\pm$ 36.8	42.6 $\pm$ 35.7	0.525
Parenting Stress Index-Short Form (PSI-SF)	Parent-Child Dysfunctional Interaction (PCDI)	32.1 $\pm$ 25.4	41.1 $\pm$ 22.6	0.134
	Difficult Child (DC)	48.7 $\pm$ 29.5	41.6 $\pm$ 29.8	0.433
	Defensive Responding (DR)	45.1 $\pm$ 37.4	39.1 $\pm$ 35.6	0.292
	Parenting Stress Index-Short Form (PSI-SF) total score	42.1 $\pm$ 29.1	41.1 $\pm$ 31.9	0.832

Statistically significant values are formatted in bold. *The empty PS and CF cells of the PEDSQL-C correspond to dimensions that cannot be evaluated in the age range of the CG study population.

3.4 Differences between the two groups

The comparison of the results between the two groups at T0 did not highlight statistically significant differences. The comparison of

both groups at T1 detects relevant changes. The analysis of the comparison between the EG and the CG at T1 shows statistically significant changes in the following scales: the PCDI scale ($p=0.036$) of PSI, and the PF ($p=0.010$) dimension of the PEDSQL-F (Table 4).

TABLE 4 Post-treatment comparison EG VS CG (results are reported as mean ± standard deviation).

		EG (T1)	CG (T1)	P
Sleep Disturbances Scale for Children (SDSC)	Disorders of initiating and maintaining sleep (DIMS)	13.4 ± 6.1	12.3 ± 3.1	0.583
	Sleep breathing disorders (SBD)	4.4 ± 2.4	3.9 ± 1.0	0.536
	Disorders of arousal (DA)	2.9 ± 1.0	3.7 ± 1.3	0.060
	Sleep wake transition disorders (SWTD)	8.0 ± 2.9	9.4 ± 2.3	0.184
	Disorders of excessive somnolence (DOES)	5.6 ± 1.9	5.0 ± 1.3	0.410
	Sleep hyperhidrosis (SHY)	3.4 ± 1.8	2.4 ± 1.0	0.100
	Sleep Disturbance Scale for Children (SDSC) total score	37.7 ± 12.7	36.7 ± 7.4	0.814
Italian Questionnaires of Temperament (QUIT)	Social orientation	3.7 ± 1.2	4.2 ± 1.1	0.242
	Inhibition to novelty	3.1 ± 1.2	2.5 ± 0.8	0.179
	Motor activity	3.3 ± 0.8	2.9 ± 1.0	0.196
	Positive emotionality	4.4 ± 1.2	4.9 ± 0.8	0.231
	Negative emotionality	2.4 ± 0.8	2.2 ± 0.7	0.389
Pediatric Quality of Life 2.0 Family Impact Module (PEDSQL-F)	Attention	3.8 ± 0.9	4.4 ± 1.0	0.107
	Physical Functioning (PF)	61.2 ± 20.8	80.4 ± 11.8	0.010
	Emotional Functioning (EF)	69.6 ± 22.6	80.0 ± 20.3	0.216
	Social Functioning (SF)	68.3 ± 26.4	80.0 ± 18.6	0.209
	Cognitive Functioning (CF)	73.6 ± 18.2	78.0 ± 24.3	0.557
	Communication (Com)	73.0 ± 21.6	85.8 ± 18.4	0.108
	Worry (W)	52.4 ± 21.5	57.5 ± 28.2	0.566
	Daily Activities (DA)	46.0 ± 24.7	60.0 ± 21.8	0.127
	Family Relationships (FR)	77.8 ± 23.5	82.0 ± 17.4	0.613
	Total Score (TOT)	65.5 ± 17.9	75.8 ± 15.6	0.123
	Parent HRQL Summary Score (HRQL)	67.5 ± 19.2	79.6 ± 14.8	0.083
	Family Functioning Summary Score (FFSS)	65.9 ± 22.2	73.8 ± 15.0	0.311
	Physical Functioning (PF)	46.7 ± 24.7	46.6 ± 30.6	0.988
	Physical Symptoms (PS)*	62.8 ± 16.8	-	-
	Emotional Functioning (EF)	71.7 ± 23.9	76.0 ± 13.3	0.597
Pediatric Quality of Life (PEDSQL-C)	Social Functioning (SF)	60.5 ± 27.3	68.0 ± 19.9	0.438
	Cognitive Functioning (CF)*	32.5 ± 37.2	-	-
	School Functioning (SchF)	56.9 ± 18.6	72.8 ± 22.1	0.163
	Psychosocial Health Summary Scale (PsyHSS)	62.5 ± 20.8	72.4 ± 16.1	0.188
	Physical Health Summary Scale (PhyHSS)	48.6 ± 25.0	46.6 ± 30.6	0.842
	Total Score (TOT)	56.7 ± 18.5	63.2 ± 19.8	0.368
	Parental Distress (PD)	55.4 ± 31.5	42.6 ± 35.7	0.303
	Parent–Child Dysfunctional Interaction (PCDI)	60.2 ± 23.6	41.1 ± 22.6	0.036
	Difficult Child (DC)	54.0 ± 32.9	41.6 ± 29.8	0.310
	Defensive Responding (DR)	47.4 ± 30.1	39.1 ± 35.6	0.489
	Parenting Stress Index-Short Form (PSI-SF) total score	57.6 ± 29.4	41.1 ± 31.9	0.152

Statistically significant values are formatted in bold. *The empty PS and CF cells of the PEDSQL-C correspond to dimensions that cannot be evaluated in the age range of the CG study population.

4 Discussion

This study explored the effects of a music therapy intervention during the hospitalization of children with CP, together with their

parents. In addition to the intensive neurorehabilitation program, a personalized music therapy project with the EM was implemented. We studied its effect on sleep quality, temperamental characteristics, quality of life, and parental distress.

Our findings showed in the EG improvement in the quality of sleep, particularly in initiating and maintaining sleep (DIMS), and sleep–wake transition disorders (SWTD), not found in the CG.

These findings confirmed the results of our previous study (39).

Previous studies (8, 40) showed that children with CP had more difficulty sleeping than the control group. In particular, the experimental group has more difficulties in initiating and maintaining sleep (DIMS), arousal disturbances (DA), and complications in the sleep–wake transition (SWTD). In our study, which integrates EM into the rehabilitation design, we saw an increase in two of the three impaired sleep areas. In addition, sleep disturbances were negatively correlated with the quality of life of children with CP (41) and their caregivers (8). Therefore, it is very important to evaluate this aspect in the care of children with CP. In support of this, the review by de Almeida et al. underlines how the motor impairment and consequent sleep disturbances of children with CP affect the health of the parent due to the night care required. This shows that high levels of stress, amplified by sleep deprivation, cause a negative impact on the quality of life of the parent and child (8). In addition, a relationship between motor impairment and sleep disturbances was found by Bautista et al. It was observed that children with GMFCS level 5 had more severe sleep disturbances due to the reduced ability to roll in bed, which led them to have more sustained waking times, more pain, and not being able to manage any airway obstructions (42).

The results of our study show that the children improved the quality of their sleep without the use of medication, despite the persistence of their problems. All this led to an improvement in the child's quality of life and a statistically significant difference in the parent's quality of life.

In addition, the active role and commitment of the parents, during the EM music therapy sessions, allowed them to acquire new strategies for the affective containment of children in facilitating the transition to sleep.

Even more, we can hypothesize that the specific EM element responsible for this improvement also comes from the creation of custom musical compositions. Listening to and interacting with one's own sound story (personalized composition) produced a condition of relaxation in the child during and after the music therapy session. Our hypothesis is supported by feedback from some parents, who reported that the effect of relaxation lasted until the following morning.

Therefore, we believe that music therapy coupled with multisensory stimulation has had a great impact on the child and the parent. This could explain the results obtained even with a limited number of therapy sessions. EM music therapy is not only related to the auditory system. It extends its sound action through the implementation of images and tactile sensations that correspond congruously to the representation of sound. For example, if different types of water sounds are played (water droplets, tap water, waterfalls, sea, etc.), the patient, while handling a cushion filled with water, simultaneously sees projected images of the corresponding sound. This allows the activation of memory and attention and promotes emotional involvement.

The behavioral and emotional response of the child to others and the environment, investigated by the QUIT, in EG highlights a statistically significant improvement in the expression of positive emotions, not found in CG. No relevant improvement in EG was observed in attention, as this aspect was not a direct object of music therapy intervention. Furthermore, comparing the results in this subscale at T0, a significant difference emerges between the groups

(the CG showed a better score than the EG), while no differences emerge at T1 (at this point we observe a better score in the EG and worse in the CG compared to previous step). This data in EG can be explained by the parent's learned ability to provide adequate stimulation and capture positive expressions, even minimal, from the child. In addition, we interpreted the statistically significant change in the attention variable of the CG as a possible effect of rehabilitation treatment. Although EG parents reported an improvement in their children's attention span, which can also be seen in video recordings of EM sessions, paradoxically this field did not emerge from the tests. In our opinion, questionnaires may not be suitable for verifying this.

Results do not show significant improvement in parental distress in EG, as in CG. However, comparing the two groups emerged differences between EG and CG in T0 and T1 in Parent–Child Dysfunctional Interaction (PCDI). Analyzing qualitatively, scores in this sub-scale highlight a slight improvement in the EG compared to a worsening in the CG. These results can be explicated by the capacity of EG parents to care for and manage the critical aspects of their child using new coping strategies acquired during the music therapy training.

Previous studies demonstrated poorer quality of life in mothers and caregivers of children with CP (8, 43, 44), special in social functioning. A study by Glinac et al. (43) demonstrated that the quality of life of CP children's mothers does not depend on the increase in the child's motor skills. Comparing this finding with the results that emerged in ours, we could therefore hypothesize that the quality of life of mothers is positively affected by interventions not directly aimed at the physical rehabilitation of the child. Our study showed a significant improvement in the quality of life of the EG family; particularly in the Emotional Functioning, Social Functioning, Worry, and Daily Activities subscales and in the Total Score and Parent HRQL Summary Score. No changes emerge in CG. These results can be explained by the parent's chance to experience acceptance and discover another key to understanding and managing their child using EM training.

Instead, the PEDSQL-C results documented an improving trend without reaching statistical significance. The trend of EG compared to CG showed improvements in the variables of the Emotional Functioning, Physical Functioning, and the Physical Health Summary Scale. This could be explained by considering the clinical complexity and variability shown by children with CP. The reduced number of case studies could be the reason for not achieving a statistically significant difference.

Many EG parents have reported that their children during EM training were motivated to give motor, communicative, and visual attention performance that did not emerge in other life or rehabilitation contexts. They also reported a positive change in their relationship with their child, which is particularly critical for a child with a disability. However, the assessment scales selected at the start of the study were not sensitive to these parent-reported changes, some of which were unexpected. For this reason, we are currently evaluating new assessment methods that are better suited to detect the changes that emerged during this study.

Despite the improvements observed, some of the investigated variables do not improve, like sleep breathing disorders (SBD) and quality of life of children, because they are directly linked to the organic component compromised by CP. Likewise, in social orientation, motor activity and attention there are no significant improvement, maybe because they are not the main goal of EM music therapy. The EM acts on the caregiver-child interaction; this is probably the reason why the emotional structure of family

relationships does not change while other aspects related to the caregiver-child relationship improve in statistically significant way.

Among the biases of the study should be considered the small number of cases studied and the limited time of treatment with EM, related to the duration of hospitalization of the children.

5 Conclusion

Our study suggests that music therapy with the Euterpe Method has beneficial effects on fundamental aspects of the child's and his parents' lives, such as sleep, emotion control, and quality of family life. These improvements are particularly relevant considering that they occur during a stressful period of hospitalization. Music therapy with the Euterpe Method makes a valuable contribution to the rehabilitation process, creating a context in which the child and parent are an active part of the treatment and the target of the care.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical approval was not required for the study involving human samples in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

TL: Conceptualization, Methodology, Writing – original draft, Investigation, Writing – review & editing. SB: Resources, Writing – review & editing. MR: Writing – review & editing, Supervision,

Funding acquisition. FD'A: Investigation, Visualization, Writing – original draft, Writing – review & editing. SS: Resources, Writing – review & editing. EN: Investigation, Writing – original draft. MD: Investigation, Writing – original draft. SP: Formal analysis, Writing – original draft, Writing – review & editing, Visualization. RG: Writing – review & editing. EC: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Glossary

EM	Euterpe method
CP	Cerebral palsy
EG	Experimental group
CG	Control group
GMFCS	Gross Motor Function Classification System
SDSC	Sleep Disturbance Scale for Children
DIMS	Disorders of initiating and maintaining sleep
SBD	Sleep breathing disorders
DA	Disorders of arousal/nightmares
SWTD	Sleep–wake transition disorders
DOES	Disorders of excessive somnolence
SHY	Sleep hyperhidrosis
PEDSQL-C	Pediatric Quality of Life of infants, toddlers, and children
PEDSQL-F	Pediatric Quality of Life of parents
PF	Physical Functioning
PS	Physical Symptoms
EF	Emotional Functioning
SF	Social Functioning
CF	Cognitive Functioning
TOT	Total Score
PsyHSS	Psychosocial Health Summary Score
PhyHSS	Physical Health Summary Score
Com	Communication
W	Worry
DA	Daily Activities
FR	Family Relationships
HRQL	Parent HRQL Summary Score
FFSS	Family Functioning Summary Score
PSI-SF	Parenting Stress Index-Short Form
PSI-SF	Parenting Stress Index-Short Form
PD	Parental distress
PDCI	Parent–child dysfunctional interaction
DC	Difficult child
DR	Defensive responding



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Early parental vocal contact in neonatal units: rationale and clinical guidelines for implementation

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This paper aims to present clear and evidence-based proposals for the integration of Early Parental Vocal Contact into the clinical practices of neonatal units. In the first part, we present a comprehensive rationale exploring the ontogenesis of voice perception in both term and preterm newborns that establishes a foundational understanding. This knowledge serves as a crucial starting point for developing evidence-based auditory and multisensory interventions aimed at fostering the developmental trajectory of preterm infants. Drawing insights from neuroscience and brain development, our proposals underscore the significance of tailoring auditory environments within neonatal settings. Special attention is given to the unique needs of preterm infants, factoring in their gestational age and maturation levels. In the second part clinical guidelines for implementation are provided and healthcare professionals are supported to assist parents in modulating their vocal interactions, aligning them with the infant's responses. Furthermore, we provide practical suggestions for engaging in discussions with parents about the content, duration, and frequency of vocal interventions. Finally, we delve into the potential roles of caregivers, parents, and health professionals within this enriched parental vocal interactional environment. Our perspective is firmly grounded in an infant and family-centered developmental care philosophy, aiming to enhance the overall well-being and the neurodevelopment of preterm infants in neonatal units.

KEYWORDS

preterm infants, early vocal contact, maternal voice, guidelines and recommendations, early intervention

1 Rationale

1.1 Developmental outcome and language development of preterm infants

Preterm infants, especially those born very and extremely preterm, remain at risk of neurodevelopmental impairment. They are particularly at risk for cognitive disorders (1) for delays in language development (2) and also for psychiatric disorders (3). Many medical factors account for this higher risk of altered neurodevelopmental outcome, but environmental

factors during critical periods of brain development are also involved (4). During the equivalent of the third trimester of gestation, brain development is mainly sensory driven. Epigenetic factors are apparently involved in this environmental shaping of the developing brain during sensitive periods (5) as are synaptogenesis and selective elimination of synapses during early stages of brain development (6).

The postnatal environment of preterm infants in the neonatal intensive care unit (NICU) differs markedly, in different modalities (7), from the environment they should have continued to encounter *in utero*, especially in the acoustic environment (8, 9). This new hospital environment exposes preterm infants to excessive sensory stimulation (loud and unpredictable noise, high light levels and strong odors) as well as to sensory deprivation (lack of biological sensory stimuli coming from the mother, due to early separation) that can alter their well-being and may interfere with their neurodevelopment and growth (10–12). The acoustic environment in the NICU is particularly deleterious, and this loud, highly pitched, unorganized, and unpredictable noise can contribute to the neurocognitive burden of preterm birth, leading to attention deficit disorders (13), and potential alterations in early communicative skills (ref Kihn, Filippa chapitre).

Speech and language impairments are common in preterm infants. Speech is how we say sounds and words and includes sounds articulation, vocal production and fluency of speech, i.e., rhythm. Language refers to the words we use and how we use them to share ideas and get what we want. Language includes words meaning, sentence construction. Preterm infants commonly develop speech and language impairments as they mature with delays in the acquisition of expressive language, receptive language processing, and articulation, and deficits in phonological short-term memory (14). These impairments include problems with receptive language processing and expressive language production and deficits in phonological memory (2). A systematic review showed that preterm infants have lower scores on simple and complex language function tests throughout childhood (15). They exhibit decreased auditory discrimination, difficulties in maintaining active auditory attention, and also greater difficulties in vocal perception (15). Poor language outcomes of preterm infants may occur even in the absence of major disabilities, supporting a possible effect from the nosocomial (hospital) auditory environment preterm infants are exposed in the NICU. Neurosensory impairment in auditory processing is a well-known cause of speech delay in infants, highlighting the importance of auditory inputs for normal language development. However, medical factors such as intraventricular hemorrhage or periventricular leukomalacia, or other insults to the developing brain, contribute to language deficits (16).

The causes of language impairments in former preterm infants are undoubtedly multifactorial, and are associated with the extent of prematurity, neonatal illnesses, severity of illness, hearing ability, gender, language exposure in the NICU and at home, maternal educational attainment, social and environmental status of the family, and availability of early intervention services (17). Although environmental factors are not the only ones involved, the deprivation of biologically meaningful auditory stimuli in preterm infants seems especially important in leading to poor language development.

According to these observations, developmental care strategies have been designed to adapt the sensory experiences of preterm infants in the NICU to their sensory expectations.

and capabilities (18). They aimed to enhance the access of preterm infants to the voices of their own mothers. Strategies such as

parent-driven language enrichment in the NICU have been shown to mitigate speech delays among preterm infants and improve their language performances (19). Recently also, it has been shown in 63 very preterm infants, with gestational age at birth below 32 weeks, that exposure to the parents' speech was positively associated with the preference for faces over non-face patterns and with the preference for parents over unfamiliar faces at the corrected age of 7 months (20). In that bi-centric study, the median of exposure to parents during the 2 weeks recordings was 8.3 h for mothers and 1.3 h per day. This led to a calculated exposure to the parent's speech ranging from 31,146 to 118,096 words for 2 weeks for the mothers, and from 151 to 13,440 words for the fathers. This suggests that Early Vocal Contact may support early social development in infancy.

1.2 Ontogenesis of voice perception

Among human voices, the maternal voice is the most prominent vocal stimulus.

accessed by full-term newborns. The specific preference of a term newborn for its own mother's voice has been well documented (21). The existence of a prenatal imprint of the mother's voice has been shown by other authors in full-term newborns in their first 2 h of life (22). The mother's voice, with its rhythmic patterns, intonation, and timbre, provides a salient and familiar auditory environment for the developing fetus, which helps in forming early neural connections and auditory processing skills (23). Recognizing the significance of prenatal auditory experience is essential to better understand the profound effect that an atypical auditory environment can exert on preterm infants during their hospitalization.

Newborns exhibit a remarkable predisposition toward voices, demonstrating an innate orientation and sensitivity to auditory stimuli from the moment of birth (24). This orientation to voices is evident in their specific responsiveness to vocal sounds compared to other auditory inputs (25). From birth, infants possess the cognitive and physiological mechanisms necessary to process and interpret auditory information, including voices, within their surrounding environment (24).

Even in the early stages of development, newborns demonstrate the ability to discriminate between different voices, distinguishing familiar voices such as those of their parents or caregivers from unfamiliar voices (26).

Moreover, newborns display preferential attention toward human speech, particularly the rhythmic and melodic features inherent in language, indicating an early sensitivity to the prosodic elements of communication (27). This early orientation to voices underscores the importance of auditory stimulation and vocal interaction in promoting infants' cognitive, linguistic, and socio-emotional development from the very beginning of life.

Preterm infants can perceive human voice, as they can exhibit positive responses to human voices (28), similar to the signs of approach described in the synactive theory of development of the NIDCAP program (29). The results of an observational study confirmed that very preterm infants differed in their physiologic responses to human speech and non-biological NICU sounds. They displayed specific autonomic responses to human voices such as significant increases in respiratory rate and decreases in heart rate without any drop in cerebral oxygenation (30). The reductions in heart

rate were similar to the responses of the orienting cardiac reflex to stimuli of particular interest (31, 32) and observed in near-term fetuses exposed to vocal stimuli (33).

Preterm infants appear able to integrate fine language differences at a cortical level and have an early ability to activate brain regions involved in linguistic processing (34). A functional optical imaging study showed that preterm infants could distinguish between two syllables (“ba” and “ga”) and between two human voices (male and female), beginning at 29 weeks post menstrual age (35), indicating that their cortical circuits could process speech even at an immature stage with incomplete layers of cortical organization.

Human speech sounds are unique signals that are essential for the subsequent language development of newborns, especially those born preterm (36, 37).

Preterm infants can also specifically perceive their mothers’ voices prior to their term-corrected age. However, the degree of exposure of preterm infants to their own mothers’ voices is highly dependent on the implementation of infant and family-centered care strategies. Many studies have evaluated the responses to the mother’s voice of preterm infants and its benefit for their well-being (38). They indicate that they can perceive their own mother’s voice, speaking the mother’s native language and using motherese infant directed speech. However, there are differences between very preterm infants and full-term newborns in recognition capabilities (39) and also in brain processing (40). Within the initial week of their life, preterm infants with a post menstrual age of 30 ± 2.5 weeks experience a decrease in heart rate when exposed to maternal sounds compared to when they are not exposed (12). This finding aligns with the observed decrease in heart rate, along with a cardiac orienting response, in foetuses with a gestational age of 32–37 weeks when they hear their mother’s voice (41). The ability to perceive his or her own mother’s voice has been also evidenced in preterm infants at around 34 weeks of corrected age, (12, 42, 43). The specific auditory activation measured with fMRI in the left superior frontal cortex of fetuses of GA 33 weeks following mother’s voice exposure (23) indicated also a possible neural basis for this response.

Preterm infants can also physiologically respond to the mother’s voice from 30 weeks PMA and repeated exposure to maternal sounds of preterm infants of mean GA 30 weeks (range, 25–32 weeks) during the first month of life may enhance the anatomical development of their primary auditory cortex (44). This suggests an adaptive and experience-dependent brain plasticity specific to maternal sounds.

1.3 Maternal voice, infant-directed speech and singing for infants’ development

The speech addressed to infants is vital to their development. Infant-directed speech can contribute to the early development of language by improving the recognition of native vowel sounds, enabling the identification of individual speech units, offering clues about grammar, supporting the comprehension of sentence structure, and the acquisition of new words (45, 46). More specifically, infant-directed speech, including amplified vowel sounds, enhances their clarity and facilitates infants’ perception, and it frequently includes simplified and repetitive speech patterns that assist infants in breaking down speech into meaningful segments (47). Infant-directed speech

offers also linguistic clues, like as intonation and stress patterns, which aid newborns in comprehending the language’s structure (48).

Furthermore, infant-directed speech facilitates the transmission of emotional states to newborns, hence promoting emotional connection and bonding between the carer and the infant (49). Through the employment of melodic, high-pitched tones Infant-directed speech is one of the various parental vocalizations used to sustain the attachment process between carers and infants, and infants are especially responsive to it (50). Intonation is a key element in infant-directed speech, it captivates infants’ focus and it is particularly informative for preverbal infants about the speakers’ communicative intent (51). On the cognitive side, it guides infants’ attention toward pertinent stimuli in their surroundings, aiding them in concentrating on crucial information and acquiring knowledge from their environment (52). Carers can in fact efficiently direct infants’ attention to objects, events, or activities of interest by manipulating the pitch, rhythm, and intonation of their voice. In addition, infant-directed speech functions to indicate that the newborn is the intended receiver of communication, so informing the infant that they are the primary focus of the caregiver’s attention and interaction (53). This facilitates infants’ comprehension that speech is specifically aimed at them and promotes mutual involvement in social exchanges.

Infant-directed speech serves to notify infants about the adult partner’s purpose to impart new knowledge to them. This signals the caregiver’s preparedness to participate in joint attention and shared activities (54, 55). Through the utilization of infant-directed speech, carers demonstrate their readiness to offer assistance and direction to newborns as they embark on their educational path.

Overall, the parental voice has a significant and complex impact on infant development, long before the first word’s appearance. Considering the crucial significance of the parental directed voice emphasizes the need to encourage early positive parent-infant interactions and create environments abundant in maternal vocalizations to enhance optimal infant development.

1.4 Early vocal contact: rational and evidence

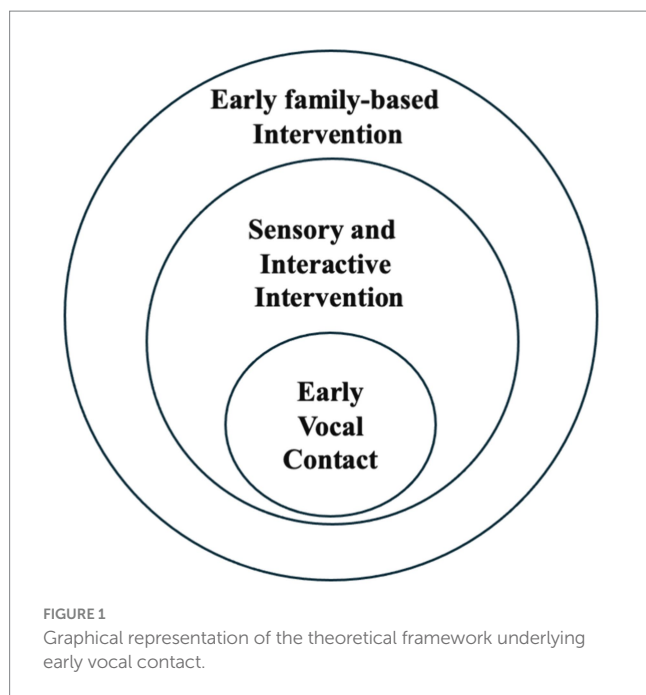
In contrast to passive stimulation techniques like recorded voice administration (44), Early Vocal Contact is a sensory and interactive intervention providing directly by parents, using infant-directed speech and songs. It facilitates a dynamic and reciprocal exchange between parents and young children (42).

This approach aligns with family-centered interventions in that, as depicted in Figure 1, it seeks to reactivate innate parenting abilities that might otherwise be latent in the atypical circumstance of preterm birth.

In previous research, compelling evidence of the beneficial effects of maternal singing and speech on preterm infants’ well-being was demonstrated (53).

As is the case with interventions utilizing recorded maternal voice, the evident effect of the Early Vocal Contact (EVC) is to stabilize infants’ physiological parameters, also decreasing critical cardiorespiratory events, such as apneas or bradycardias (43, 56, 57).

The maturation of the autonomous nervous system was found to be enhanced after two weeks of EVC during hospitalization, with a specific activation of the preterm infant’s parasympathetic activity (58,



59). Preterm infant-directed singing enhanced their autonomic stability (60) and decreased maternal anxiety (61). Preterm hospitalized newborns regulate their behavior in response to the acoustic properties of infant-directed speech when they hear a familiar voice addressing them (62).

During the EVC interesting infant behaviors were observed and analyzed using the System for Coding Perinatal Behavior (62). This coding system has been developed to analyze video frames by frame. The system seeks to recognize and consistently code the complex behavioral patterns in fetuses, preterm neonates, and full-term neonates from the last trimester of pregnancy to the first month following delivery. The vocalization of the mother induces premature infants to initiate eye contact and increases their self-regulatory actions, such as engaging in self-touch (62).

Finally, maternal speech and singing play a protective role against pain for preterm infants, offering a nonpharmacological intervention to alleviate pain in these vulnerable neonates. Research indicates that maternal vocalization, including both speech and singing, can effectively mitigate pain responses and enhance coping mechanisms in preterm infants during medical procedures (63).

It was recently found that maternal speech reduces pain scores and increases oxytocin levels in preterm infants undergoing painful procedures, further highlighting the positive impact of maternal vocalization in alleviating pain and promoting comfort in preterm infants (64). Overall, these findings underscore the importance of EVC in neonatal care settings, providing valuable insights into the potential mechanisms through which maternal vocalization can enhance the physiological and behavioral stability of preterm infants.

Moreover, mothers who engage in singing and talking to their premature infants during painful medical procedures experience an increase in oxytocin levels and a decrease in anxiety, indicating the potential therapeutic benefits of maternal vocalization for both mothers and infants during stressful situations (40).

At a brain level, a repeated exposure to infant-directed singing during infant's hospitalization was positively associated with improved auditory discrimination of phonetic and emotional speech sounds in preterm infants at term age (65). Moreover, the continuous exposure to the maternal singing during skin-to-skin contact leads to larger neural responses to changes in speech sounds, interpreted as a more mature brain response to speech discrimination of preterm infants at term equivalent age (66). Interestingly, while exposed to the maternal singing preterm newborns increased their cerebral oxygenation (67). Further investigation is warranted to determine the subtle brain responses of preterm infants to maternal singing, both in terms of brain localization and brain electrical brain responses across different frequency bands.

Some of the overmentioned findings are summarized in Figure 2.

In the various studies evaluating the EVC, the total duration of the mother's voice sessions lasted from 10 to 20 min per day, three times per week, for 2 weeks or until discharge. Other research has shown a correlation between the number of words to which preterm babies are exposed and their subsequent language development, suggesting that dosage may be important and that the benefits are related to the dosage effect (Table 1).

Daily language exposure, beyond the EVC sessions, is likely a crucial factor in the development of preterm infants. When discussing the EVC intervention, it is important to take into account both the potential risks of language deprivation and the dangers of overstimulation. No studies have been conducted to precisely investigate the dosage effect and to evaluate whether higher exposure (for instance, 20 min every day) could provide greater benefits compared to the already evaluated dosage. These studies should be conducted to ensure that more exposure is not detrimental and could indeed be beneficial. In any case, additional exposure should be based on the evaluation of the infant's response.

To conclude, prior research has emphasized the importance of parental vocalizations, showcasing its ability to improve the physiological stability, emotional regulation, and attachment to carers of infants. EVC offers a nurturing environment for the infant's development, and promotes direct vocal interaction between parents and infants, which enables the exchange of emotional cues. This reciprocal intervention enhances the sensory encounters of premature infants and enables parents to engage actively in their child's care, thereby potentially supporting long-term synchrony within the familial framework.

2 Proposal for good implementation in the clinical practice

The practice of EVC is based on the principles of infant and family centered developmental care (18, 68). This implies to provide a supportive sensory environment to the infant that will allow him/her to perceive infant directed speech in an intimate and secure environment supporting also parents for speech privacy (Kuhn et al., (68)). Embedded in the concept of infant centered care is also the need to individualize the care, founded above all on observation of the signs of approach and withdrawal that the baby may show in response to live vocal stimulation (69, 70). The last cornerstone of IFCDC is to have a family centered approach and to support the parents to attune the intervention to the infant's responses and sensory expectancies.

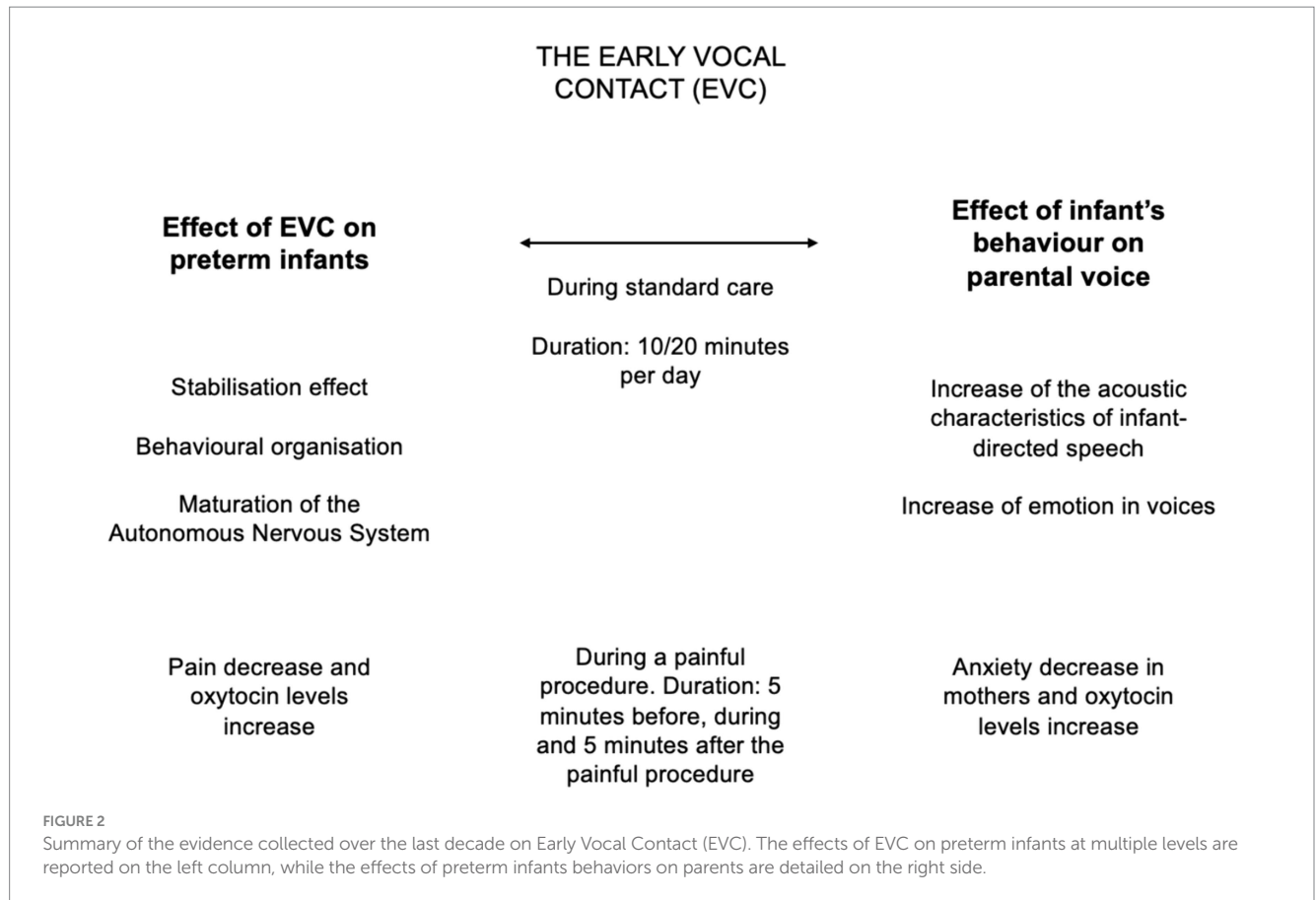


TABLE 1 Summary of the practical recommendations for EVC.

Recommendations	For parents	For the medical team
Observe the baby's approach and withdrawal signs	The principles of individualized care are based on observing the baby's approach and withdrawal signs	Parents should be guided to recognize these signs and to modulate their vocal intervention accordingly (i.e., interrupt if there are withdrawal signs)
Modulate the voice	Parents' direct voice is modulated (duration, intensity) based on the baby's reactions	Risks of overstimulation are significantly reduced when the voice is modulated
Optimal conditions	Calm wakefulness or undifferentiated sleep state, or during transition states	- Baby in skin-to-skin contact, in a multisensory context with bone conduction of sounds - Baby in an incubator (voice 10–15 dBA above ambient background noise)
Intimacy context	Intuitive parental skills become active in an intimacy context	Ensure, as with skin-to-skin contact, an intimacy context where parents can address their baby
EVC and pain	Maternal and/or paternal voice can be useful to reduce pain	Stabilization of the baby to promote blood intake and faster return to calm in association with other non-pharmacological analgesic strategies (non-nutritive sucking, sweet solutions, skin-to-skin)
Limits	Early vocal contact with extremely or highly unstable preterm babies?	Individual responses guide the type and duration of contact (physiological responses and late or unexpected behavioral responses that are difficult to read)

2.1 Which is the ideal environment for the EVC?

First, to preserve speech privacy and audibility, the best would be to have a supportive NICU design with the infant and the parents in a private family room. It has many benefits for the infant and the parents (71) with lower background noise levels as

compared to open bay NICUs or rooms with multiple bed (72, 73).

Second, an ideal environment for the infant is provided by a positive multisensory experience of the parent with intermodal redundancy (11, 74), i.e., skin to skin contact (75). Skin-to-skin contact can allow EVC to be transmitted via bone conduction, through the parent's chest, and thus limits the loudness required for audibility.

Moreover, it offers multiple benefits to the infants and the parents (75). It supports respiratory function, provides better temperature control, promotes sleep, and decreases stress in the infant, who becomes calmer and in a more stable condition to experience and benefit from EVC. Third, when the baby is in an incubator, parents should be advised to open the doors to speak to him/her. In that case, for the voice to be perceptible, it must be at a level of 10–15 dbA above the background noise (76). The background noise should be the lowest possible but noisy environment are still frequent in the NICU, especially if the infants is on nasal continuous positive airway pressure. For EVC to be natural and beneficial for both parents and baby, a context of intimacy must be provided - as with skin-to-skin contact - where adults can talk to their baby without fear of being judged or disturbing the space of other families. Thus, it is important to decrease the exposure to high sound pressure levels as much as possible whatever the nearby environment of the infant. It is therefore very important to develop and implement efficient sound abatement measures, lessening sound pressure levels and attenuating their variations near the infants. Adapting architectural design and technical equipment in the NICU to the sensory abilities of preterm infants and implementing adequate care organizations may help reduce iatrogenic noise hazards and promote access to EVC (77). The implementation of a quiet hour or the use of noise sensor light alarms has been shown efficient to sensitize medical and nursing teams and to reduce noise in the neonatal ICU (78). There has been new recommendations issued by the American Association of Pediatrics very recently that should be implemented (79) regarding the prevention of excessive noise exposure in infants.

2.2 Which is the infant's optimal behavioral state for delivering the early vocal contact?

There are no studies evaluating precisely this question and data allowing to issue strong guidelines are lacking. However, the optimal conditions for delivering EVC would certainly be in a state of calm wakefulness (quiet awake) or indeterminate sleep when using the Prechtl's classification of behavioral state (80). Preserving deep sleep and active sleep remains imperative, but when the baby's eyes are open or when he is in a state of transition between these two states, he is more likely to pay attention to significant sensory stimuli (81). This is when parents can make their presence felt and support the transition from one state to the other. We know from previous studies that infants are more responsive to their auditory environment when they are in active sleep state (76, 82) a state in which sleep disruption may occur also after sound peaks (83). Thus, when the infant is sleeping and during skin-to-skin contact for instance, EVC could be provided but should be fully attuned to the infant's close behavioral observation. Moreover, the results derived from a pioneering study on EVC (43), may suggest that parent talking would support quiet awake state, whereas parent singing would preserve sleep. Based on these observations, we may propose parents to provide singing at the onset of skin-to-skin contact especially during the transition from the incubator. This could help to better support the self-regulation competencies of the infant during this potentially stressful phase. Additionally in the last phase of skin-to-skin contact, parents may talk to their infants to gradually awake them, if desired to enhance social interaction and to prepare the infants for care.

2.3 The importance of attuning with the infant's responses

The practice of EVC is based on the principles of individualized care and is founded above all on observation of the signs of approach and withdrawal that the baby may show in response to live vocal stimulation (69). Parents should be guided to recognize these signs and to modulate their vocal intervention accordingly. These signs may indicate destabilization or over-stimulation. Unlike the recorded voice transmitted through loudspeakers or headphones, the parents' direct voice can be modulated, either in terms of duration or intensity, according to the baby's behavioral and physiological reactions. The risks of over-stimulation are therefore significantly reduced compared with the administration of music or the recorded parental voice. We therefore suggest observing the baby's behavioral and physiological reactions with the parents and individualizing the intensity and duration of vocal contact. Indeed, the gestational age of the infant also modulates its response, and the very, and even more, the extremely PI may also react more physiologically in the first weeks of life (70). These responses need to be considered and the modalities of the EVC adjusted carefully to these responses.

The effects of a EVC between parents and very premature infants with serious health complications or very immature infants are currently unknown, as most studies on the effects of direct maternal voice and, in general, on multisensory contact are limited to premature infants in stable conditions (59, 84).

The precise time of onset of EVC must be judged individually and full account must be taken of the condition of each baby and its mother or father. The very preterm newborn's responses to intervention should guide the type and duration of EVC: late or unexpected physiological (bradycardia, apnea) and behavioral responses in preterm newborns are often difficult to read, especially by parents. Before the EVC, infant's conditions must be stable, but they do not necessarily have to be optimal as parents and babies can both benefit from this intervention, and improve their physiological and behavioral well-being as a result of this early practice (61). According to parental reports, a gentle and soft humming sound during skin-to-skin contact was found to be the appropriate level of intensity for their extremely premature baby.

The complexity of the vocal interaction can widen with increasing gestational age. Close observation of the infant, as part of the NIDCAP program (69) may be useful to reassure the parents and the caregivers about the comfort of the infant. Future studies are warranted to address these questions and would help to define more evidenced based proposals.

2.4 Intuitive adaptation and synchrony: two key concepts for describing vocal communication between parents and infants

Adaptation, as it pertains to parental voices, denotes the ever-changing dynamic modulation by which parents modify key acoustical features of their vocalizations - such pitch, timbre, energy and rhythm, of their discourse in order to correspond with the developing requirements and capacities of their newborn (85). This procedure

conforms to the tenets of progressive development and mirrors the cognitive and affective maturation of the infant.

Adaptation is an ongoing and gradual process that mirrors the incremental transformations that occur throughout the infant's developmental trajectory, and age is a better predictor of changes in parental speech than socioeconomic position or other family parameters (86, 87). Carers adeptly adjust the qualities of their vocalizations in accordance with the developing cognitive and sensory capacities of the neonate as time passes, thereby customizing their communication.

The average length of adult utterances increases as the child grows older, reflecting parental adaptation to the child's increasing language skills, and the articulation rate of the fundamental frequency and vowel duration become more similar to adult-directed speech over time, though pitch variability remains consistent (88).

The analysis of the maternal voice during EVC in the NICU, revealed an adaptation of the acoustic parameters including pitch and intensity, which undergo modulation and change in response to the baby's eye movements or smiles during the EVC (53). Furthermore, during these newborn's positive behavioral signals and instances of reciprocal modulation during the EVC, the maternal voice is perceived by naïve listeners as being more emotive and smiling (89). Indeed, listeners perceive the mother's smile while speaking or singing solely through auditory cues. A reciprocal cycle is thus established between the interacting partners throughout the EVC.

In general, the observation of parental voices adapting signifies a thoughtful and accommodating method of providing care, distinguished by a profound comprehension of the infant's physiological requirements and vulnerabilities. Carers establish a nurturing and supportive atmosphere that promotes the child's optimal development and well-being by harmonizing with the infant's cognitive and affective development.

2.5 Practical modalities: the singing repertoire, the language, singing or speaking?

In recent years of research, few elements have emerged from scientific evidence to better understand the optimal practical modalities for parents to provide Early Vocal Contact and the optimal conditions for its delivery. More specifically in the following paragraph, we will reflect on what parents could sing or say during Early Vocal Contact, on the language they should chose in early communication, on the different functions that singing and speech have during the Early Vocal Contact and on the best conditions to deliver it.

Cross-cultural regularities in infant-directed vocalizations, speech, and singing have been highlighted (90), but the consistency of the frequency, context, and functions of infant-directed singing across global field sites remains controversial. Parental singing continues to be a prevalent aspect of caregiving, which is peculiar given the substantial technological advancements that have occurred in the last 30 years (91).

However, for multiple individual and environmental reasons the hospital setting profoundly changes the intuitive and spontaneous ways parents use to interact with their newborns.

Sixty percent of mothers sang spontaneously in the NICU, according to a study examining mothers' beliefs, thoughts, and vocal behavior, and there was no correlation found between mothers' spontaneous vocal use and their age, level of education or parenting experience, or musical background (92).

However, little is known about their spontaneous repertoire while spontaneously singing in the NICU. Based on our prior investigation on spontaneous maternal singing in the NICU (43), it was found that popular music constituted around 40% of the repertoire, whereas traditional national and regional melodies intended for an adult constituted 32%. The proportions of lullabies and children's music in the overall repertoire were 17 and 11%, respectively (93).

The wide variety of songs included in the selection reflects the parents' varied musical preferences, and in contrast to initial projections, parental preference prevailed over the utilization of children-oriented repertoire, including nursery rhymes and lullabies, with the preference being for the use of familiar and pleasurable adult music.

The spontaneous contents of infant-directed speech in the NICU encompass several categories and comprehend several registers.

The use of a predetermined book can be helpful for parents gaining confidence with the art of storytelling. Initially, having a set text provides structure and eases parents into the practice. However, once parents become more comfortable talking to their babies, the predetermined text becomes unnecessary. At this stage, parents can invent new stories, responding in real-time to their babies' cues and reactions, that they could not see while reading a book. Parents can also engage in emotional dialogs, modulating on their newborn's state and talking about their future together at home.

Describing the future and specific aspects of daily life outside of the hospital, such as the characteristics of their room and the individuals eagerly awaiting their return home, imbues the conversation with a profound emotional content.

2.5.1 Which language for the infant-directed speech?

Mothers were encouraged to sing and converse in their native tongues as part of all of our accepted protocols. This is because early vocal contact serves as a means of both affective attunement and adult-child sharing of cultural practices and meanings. Mother tongues store meaning and knowledge gathered by parents or other relatives, indicating that there is a continuous drive to transmit. Mother tongues are not just a specific language but also a communication mechanism utilized among kin (94).

Parents can serve as the link between cultural practice and meaning during hospitalization, when standards of care are crucial to the life of the infant. Following their discharge, preterm babies will be part of a larger sociocultural environment where parenting philosophies have a role in baby care. Early social connection through voice, mother tongue, and culturally based play songs and lullabies is necessary for early engagement in social and cultural activities, which might provide unique challenges for individualized care in the NICU. All the components of the adult's cultural and linguistic legacy that influence an infant's development are present in this early form of protoconversation.

Nonetheless, the majority of parents have already decided on the language they wish to use while speaking to their infants. Research conducted on multilingual households indicates that maintaining consistency in the first language preference enhances the overall

experience with that language and the implications of that decision for language acquisition, also affecting relative input frequency (95).

Seemingly, the use of song of kin can improve comfort, safety, stability, and sleep in infants (96). The use of songs of kin, either sung by parents or by a music therapist have positive affects when compared to standard lullabies (97). The use of songs of kin resulted in a higher sucking rate, indicating a preference for well-known music and supporting the hypothesis that these songs may be performed by a parent singing or a music therapist using songs that have been passed down through the generations or that are associated with a particularly significant event. Additionally, this might encourage non-nutritive sucking as an entrainment for healthier eating habits.

2.5.2 Do preterm infant-directed speech or songs in the NICU serve different purposes?

In humans, ID speech and songs are universal and fundamental communicative signals for establishing contact and attachment between parents and helpless infants needing continuous care over multiple years (98).

Acoustic similarities allow listeners belonging to different cultural contexts to correctly identify infant versus non-infant directed speech and songs (90), independently from the effects of linguistic relatedness between vocalizer and listener.

Different functions of ID speech and songs have been highlighted during infant development (99) and these differences are also evidenced by the specific context, such as soothing or play contexts (100).

Differential effects of ID speech and songs directed to preterm infants have also been highlighted, which might suggest that these two universal forms of communication aimed at the young of our species may have different functions.

One notable effect is on the stabilization of the infants; both speech and songs contribute equally to stabilization, though they modulate the infants' states differently (43). Infant-directed speech tends to increase the awakeness in preterm infants, while during singing they tend to remain in their initial state of quiet sleep. When it comes to behavioral organization, both forms of communication support similar self-regulation processes. However, singing uniquely induces rhythmic mouth movements in the infants and speech increases non-rhythmic mouth movements (62). This is probably due to the repetitive structure of the infant-directed singing, eliciting rhythmical responses in preterm infants. Regarding emotional attribution, both speech and songs elicit more emotion during positive communicative behaviors, such as eye opening and smile, but speech is perceived to convey more emotion compared to singing (89). This difference can be explained in terms of musical structure. In songs, the melody imposes constraints on pitch variability and tempo, limiting the expressiveness that can be achieved through these elements. Consequently, speech, which is not bound by such musical constraints, allows for introducing greater variability, thereby allowing listeners to perceive more differences in emotional contents. In terms of pain management, there are differential effects on the infants' pain and oxytocin levels, with speech having a more pronounced effect on perceived pain reduction, but this difference was not significant.

Despite these differences, both speech and singing result in similar increases in maternal oxytocin levels, with the impact of speech being more apparent.

Finally, only maternal singing modulates the heart rate variability response in preterm infants when exposed to the maternal voice, suggesting that maternal singing—but not speech—significantly sustains the parasympathetic activity of the autonomic nervous system in (40).

In conclusion, both infant-directed singing and speech should be sustained during EVC between parents and preterm infants, as they have differential effects, and they potentially serve different functions in the communication.

2.6 Simple recommendations on how to support mothers/fathers for the EVC

In the following lines some key recommendations to support parents in the EVC are reported:

- Creating a condition of intimacy within the hospital room.
- Sensitizing parents on the need to be attentive to the infant's responses, as the vocal contact is a dynamic dialog and not a sensory administration of a stimulus.
- Supporting parents in reading their preterm infants' positive and negative responses to vocal contact.
- Encouraging parents to speak during the different phases of a routine painful procedure: in the preparation phase, during the procedure, and after it.
- Sustaining the parental humming, singing, and speech in a multisensory context, such as during skin-to-skin contact.
- Helping parents pay extra attention to the most fragile preterm infants, who can have negative responses to many simultaneous sensory stimulations.

To summarize, simple and clear messages should be conveyed to parents in the NICU.

First, it should be emphasized that the primary caregiver's ability to intuitively sing and speak addressed to their infant is fundamental because it ensures the continuity and consistency of the caregiving relationship, which is critical for the child's long-term development and well-being. When parents take on the role of the main communicators through vocal and auditory means, they create a special bond with their child that is marked by intimacy, confidence, and emotional attachment. This connection serves as the foundation for the child's socio-emotional growth and language development, shaping their worldview and future relationships (101, 102).

Secondly, it is important to highlight that regular vocal interactions between parents and their newborn create a richer environment, leading to long-term benefits for the child's linguistic and socio-communicative development. This helps establish a strong foundation for future learning and social skills.

Additionally, parents should be aware that their child's sense of security and attachment is strengthened by the emotional responsiveness in their vocalizations, acting as a protective barrier against pain, adversity, and stress.

Finally, by creating a nurturing and stimulating environment, parents can experience reduced levels of anxiety themselves. Singing and speaking to their babies is beneficial for both the

babies and the parents, promoting well-being for all. It is important to note that the recommendations provided below are straightforward and practical adjustments to the care of infants that can be easily implemented by both parents and medical professionals in their daily routine.

2.7 Fathers, mothers and the EVC

Over the past few decades, a discernible trend has emerged wherein fathers are increasingly participating in the early care of their offspring. This shift can be attributed to evolving family dynamics and shifting societal norms. In the research literature, however, the specific effects of paternal intervention on infant development have received scant attention.

More specifically, there have been few studies on fathers' interventions in NICUs, with the majority focusing on basic skin-to-skin contact or tactile procedures (64). These interventions have demonstrated equal overall positive impacts on both mothers and fathers in terms of infant physiological and behavioral reactions. Notably, there was also evidence of a positive impact on the fathers' mental health, suggesting that their active involvement in caregiving can reduce stress and increase emotional well-being (64).

Including fathers as active partners in the care of their preterm newborns resulted in positive outcomes for both the infants and the fathers. The presence and involvement of fathers in the NICU have been associated with improvements in the infants' physiological stability, such as better temperature regulation and heart rate stability, and enhanced developmental outcomes (103). Fathers who engage in skin-to-skin contact and other caregiving activities also report feeling more confident and competent in their parenting role, fostering a stronger bond with their child.

Despite these promising findings, there remains a significant gap in research exploring the full potential of paternal involvement in NICU settings. Most existing studies have been limited in scope, focusing primarily on simple, direct forms of interaction. To truly harness the benefits of paternal engagement, more research is needed to develop and evaluate innovative, multimodal, and interactive interventions. These interventions should aim to provide fathers with opportunities for positive, meaningful interaction with their preterm infants, incorporating elements such as vocal communication and multisensory stimulation. By fostering a more inclusive caregiving environment that actively involves both parents, NICUs can support the holistic development of preterm infants and strengthen family dynamics from the earliest stages of life.

To address this gap, a group of researchers conducted a study to examine the direct and contingent effects of fathers' speech on premature infants.

The results reported by the authors indicated that paternal speech had comparable and noteworthy impacts on premature infants as maternal speech. More precisely, when the infants were exposed to both explicit and implicit paternal discourse, their levels of calm arousal increased, suggesting that their emotional

and physiological states were positively impacted. This indicates that the vocal interactions of fathers contribute significantly to the well-being of their infants and the development of feelings of security and comfort.

It is noteworthy that modifications in specific acoustic attributes of the father's voice were also detected during EVC with their PI (104). A father's voice displayed an elevated pitch when the infant was in an agitated state of arousal; this may indicate an adaptive reaction to the infant's emotional cues. Notwithstanding this modulation, the paternal voice tended to be more subdued in comparison to the maternal voice, underscoring possible complementary distinctions in vocal communication patterns between fathers and mothers.

In general, the results highlight the significance of paternal participation in early caregiving activities and the distinct contributions that fathers make in the context of early communication.

2.8 What is the role of other vocal contact providers?

Despite the growing interest from musicians, music therapists, and caregivers in providing additional sources of vocal contact, the primary aim should be to support parent-infant interaction and ensure that the infant has access to the parents' voices. These voices are biologically significant for the infant and have been proven to support language development.

While other vocal contact providers can play a role, this paper emphasizes the preferential and primary role of parents in early vocal interactions. It is crucial for every caregiver who interacts with the baby to understand the importance of using infant-directed speech as a primary tool during routine care. This helps initiate interaction with the infant.

When parents are not in the NICU, caregivers should strive to engage in early conversational turns with infants, participating in vocal dialogs to support an earlier onset of infant's vocalizations. This engagement fosters a more supportive and developmentally beneficial environment for the infant.

3 Conclusion

In this viewpoint paper, we aim to propose safe and effective ways to use EVC in everyday NICU settings. There is substantial rationale to support the dissemination of EVC practices in the broad context of infant and family-centered care. EVC serves as a crucial method to address the lack of exposure preterm infants have to adequate sensory stimuli, such as social interactions and linguistic utterances.

Implementing EVC can help normalize the number of words that preterm infants hear in the NICU, bringing it closer to the level of auditory exposure fetuses experience *in utero* (8). This increased exposure is essential, as the lack of adequate auditory stimulation is likely one of the causes of atypical

language and speech perception development of preterm infants (105).

Early vocal interaction is a fundamental human practice that is particularly important to integrate in the NICU routine care, for at-risk populations, such as preterm infants.

Ensuring that caregivers and healthcare professionals understand and implement EVC strategies can lead to better outcomes for both infants and their families. Therefore, it is crucial to continue researching and advocating for the use of EVC in neonatal care units worldwide.

Author contributions

MF: Conceptualization, Writing – original draft, Writing – review & editing. PK: Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The effect of live-performed music therapy with physical contact in preterm infants on parental perceived stress and salivary cortisol levels

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Introduction: Parents of preterm infants face a stressful life event which might have long term impact on the parent–child relation as well as on the infant's cognitive and socio-emotional development. Both music therapy (MT) and physical contact (PC) are stress-reducing interventions for parents and preterm infants on the neonatal intensive care unit (NICU). Meanwhile, especially close PC is considered as standard care (SC) in most NICUs. However, the effect of live performed MT with PC on parental perceived stress and cortisol levels has barely been investigated. We hypothesized that MT with PC leads to reduced stress levels and lower salivary cortisol concentrations compared to SC in parents of preterm infants during the first 4 weeks after birth.

Methods: Randomized-controlled trial enrolling the parents of 99 preterm infants (MT $n = 50$, SC $n = 49$ infants). The infants received either MT with PC or SC only. Perceived stress was measured with the perceived stress questionnaire 20 (PSQ-20) after birth and 4 weeks later. Salivary cortisol levels were obtained and measured weekly after birth for 4 weeks.

Results: Forty-two mothers and eight fathers of the intervention group (MT with PC) as well as $n = 43$ mothers and $n = 6$ fathers of the control group (SC) were enrolled. For the intervention group, salivary cortisol was reduced 4 weeks after birth [mothers 5.5 nmol/l (confidence interval (CI) 3.6–7.5); fathers 8.3 (CI 7.2–9.4)] compared to the control group [mothers 10.3 nmol/l (CI 5.4–15.3); fathers 14.8 (CI 8.9–20.7)]. Overall perceived stress scores decreased in the intervention group (mothers -17.6 ; fathers -12.6) and increased in the control group (mothers $+6.1$; fathers $+21.4$) over 4 weeks.

Discussion: Live-performed MT with PC in preterm infants might be an effective, non-invasive intervention to reduce parental stress and cortisol levels. Future studies should investigate the long-term effects of this intervention on the parent–infant relation as well as on the infants' cognitive and socio-emotional development.

Clinical trial registration: <https://drks.de/search/en/trial/DRKS00025755> identifier [DRKS00025755].

KEYWORDS

music therapy, preterm infant, cortisol, stress reduction, NICU, parents, parental stress

1 Introduction

Prematurity is defined as birth before 37 weeks' gestation. Worldwide more than 1 in 10 infants are born premature (Ohuma et al., 2023). As preterm birth coincides with a vulnerable period of brain development, preterm infants are at increased risk of neurodevelopmental impairments in later life. The risk increases with decreasing gestational age (Marlow et al., 2014; Wallois et al., 2020). Stress caused by, e.g., painful procedures, noise and parental separation has been identified as harmful factors for brain development (Cook et al., 2023; Cong et al., 2017; Zhang et al., 2022). A stress reducing, non-invasive intervention is music therapy (MT), which has gained attention in recent years (Yue et al., 2021). Previous studies showed that live and individually performed MT has positive effects on the preterm infants' vital parameters, feeding behavior and weight gain (Yue et al., 2021; Erdei et al., 2024; Kobus et al., 2021; Kraft et al., 2021). While the long-term effects of MT on clinical neurodevelopment are still under investigation, results from diffusion tensor imaging and resting-state functional imaging studies at term equivalent age hint at potential effects of MT on neurodevelopment (Sa de Almeida et al., 2020; Haslbeck et al., 2020, 2021; Dewan et al., 2024).

Not only the preterm infant faces stressful events during the treatment on the neonatal intensive care unit (NICU), but also their parents undergo a critical life event (Weigl et al., 2020; Lundqvist et al., 2019). Parents of preterm infants are also at increased risk of parental separation (Nusinovici et al., 2017). Preterm birth interrupts bonding, which negatively impacts the development of the mother-child-relationship and might have substantial effects on the quality of early infant-parent-interaction (Fernández Medina et al., 2018). Postnatal bonding is important for the infant's social, emotional and cognitive development and has positive impact on later mental health and resilience (Winston and Chicot, 2016). Following a study by Rusanen et al., postnatal bonding problems are related to socio-emotional problems in children at 2 years (Rusanen et al., 2024).

As stress negatively impacts bonding (Khoramirad et al., 2021) promoting parental well-being during the NICU stay is an important issue in developmental care for preterm infants. A promising family-centered intervention is music therapy (MT), which is live performed by a certified music therapist (Haslbeck et al., 2023). Recent studies showed that MT reduces maternal distress, anxiety and depressive symptoms (Kehl et al., 2020; Kobus et al., 2022a; Kraft et al., 2021). It also positively modulates the mothers' perception of the infant (Kobus et al., 2023).

Besides MT, the beneficial effects of physical contact (PC) between preterm infants and their parents/caregivers have been recognized and many NICUs all over the world have adopted the save practice of PC contact in developmental care for preterm infants (Bedetti et al., 2023). While most studies refer to close PC, i.e., skin-to-skin care or kangaroo care, PC might also include hand-touch only (Kobus et al., 2024). In high-income countries, close PC leads to cardiorespiratory and temperature stability, reduces pain reactions in the preterm infant and promotes sleep organization (Bastani et al., 2017; Durmaz et al.,

2023; Pavlyshyn and Sarapuk, 2023). Studies suggest its positive impact on long-term neurodevelopmental outcome (Gonya et al., 2017). In mothers, the beneficial effect of close PC includes facilitated bonding, higher rates of breastfeeding as well as reduced stress levels (Cong et al., 2021; Oras et al., 2016).

Despite the overlapping effects of both MT and PC, recent studies hint at beneficial effects of combining both practices (Teckenberg-Jansson et al., 2011; Jakobson et al., 2021; Kobus et al., 2022b) on preterm infants' vital parameters, parental well-being and parent-infant-attachment. A recent study by Span et al. found equal beneficial effects of combined live performed MT with kangaroo care on physiological parameters and neurological functioning (Span et al., 2021) in preterm infants compared to MT alone. However, Teckenberg-Jansson et al. showed more beneficial effects of combined MT and kangaroo care compared to kangaroo care alone on infants' vital parameters and parental well-being (Teckenberg-Jansson et al., 2011).

As part of a randomized-controlled trial (RCT), our group recently showed that MT with parental physical contact (close PC; or hand touch contact) has positive effects on the preterm infants' vital signs and behavior assessed with the COMFORTneo score, independent of the type of physical contact (Kobus et al., 2024).

A further aim of this RCT and the current study was to evaluate the effect of this intervention on the parental stress level by measuring salivary cortisol as well as self-rated stress levels assessed with the perceived stress questionnaire 20 (PSQ-20).

2 Methods

2.1 Study design

The aim of this prospective, randomized, controlled clinical trial was to investigate the effects of live performed MT combined with PC on salivary cortisol and perceived stress levels of parents from preterm infants during their NICU stay until 4 weeks after delivery. Study approval was obtained from the local ethics committee of the Medical Faculty of the University of Duisburg-Essen (21-9823-BO). The study was registered with the German registry for clinical studies (registration number: DRKS00025755).

2.2 Cohort recruitment

Cohort recruitment of preterm infants (gestational age (GA) < 37 + 0 weeks) started in July 2021 in a level III NICU. The cortisol and stress level analyses were performed as an exploratory add-on study, thus the power analysis relied on the primary outcome of the main study (COMFORTneo score before versus after MT, please see Supplementary material 1) (Kobus et al., 2024). Infants were excluded from eligibility for this study if not stable enough to leave the incubator or cod, or if they participated in a simultaneous

interventional trial. Infants were recruited and randomized 1:1 to either standard medical care (SC) or standard medical care plus music therapy with physical contact (MT). The intervention consisted of up to 10 sessions of MT, five each with close PC and five with hand touch only. Written informed consent was obtained from all caregivers prior to inclusion into the study and subsequent randomization. Prior to randomization and the first music therapy intervention, parents had to decide, if mother or father would accompany all therapy sessions. The participating mothers or fathers were asked to weekly collect saliva for cortisol measurements and to answer the PSQ-20 in paper form directly after randomization and for the intervention group before the first session of MT as well as after 4 weeks.

2.3 Standard physical contact between parents and preterm infants

Close PC, i.e., skin-to-skin contact or kangaroo care, is an established and standardized procedure on our NICU to promote bonding between parents and preterm infants as well as breast feeding and to enable contact to the parental skin environment. During skin-to-skin contact, the infant is placed naked (only wearing a diaper) on the parental breast/skin. A hand mirror can be used by the parent to better follow the infant's reactions. In case of (non-)invasive ventilation, the devices are secured properly. The duration of early skin-to-skin contact is set individually. During the NICU stay, skin-to-skin contact should be provided several hours a day and last at least 1 h. The first skin-to-skin contact is desirable within the first 2 h of the infant's life if mother and infant are stable enough.

2.4 Live music therapy intervention

MT was performed as previously described (Kobus et al., 2024). Briefly, MT sessions were performed individually by a trained music therapist using the instrument sansula, which creates vibrating, long-lasting and soft sounds at a low level. The infant's breathing and reactions guided the sequences. MT sessions were integrated into the clinical routine and timepoints were coordinated between music therapist, parent, and nursing staff. A maximum of 10 MT sessions were performed in clinically stable preterm infants in the presence of the determined parent three to four times per week. MT sessions were performed either with parental hand touch with the infant remaining in the incubator or (heated) cocoon or with close PC with the infant lying in the parent's arms, on the chest, legs, or shoulder. The choice between hand touch and close PC sessions was made either according to clinical needs, or the type of contact infant and parent had before the start of MT.

2.5 Salivary cortisol analysis

For the assessment of salivary cortisol levels, participants self-collected saliva in the morning after awakening using commercial collection devices (Salivette Cortisol; Sarstedt, Nuembrecht, Germany). To avoid any contamination, they were asked not to eat, drink, smoke or brush teeth before sample collection. Saliva

samples were returned to the laboratory, where the saliva was harvested by centrifugation and stored at -80° until analysis. Salivary cortisol concentrations were analyzed by enzyme-linked immunosorbent assay (Cortisol Saliva ELISA, IBL International, Hamburg, Germany) according to the manufacturer's instructions by trained staff in a laboratory that regularly takes part in round robin tests for quality assurance and method validation. Cross-reactivity of the anti-cortisol antibody with other relevant steroids was 8.5% (11-deoxycortisol), 2.6% (cortisone), 1.0% (corticosterone), and $<0.1\%$ (estrone, estradiol, estriol, progesterone, testosterone). Inter- and intra-assay coefficients of variation were $<10\%$. Salivary cortisol levels were measured weekly over the first 4 weeks. The mothers and fathers collected the cortisol samples irregularly and provided different numbers of samples per week. For the analysis, the mean values of each of the samples per week per parent were determined.

2.6 PSQ-20

To quantify the perceived stress level of the participating mother or father before the first session of MT and 4 weeks later, the PSQ-20 was handed out to both the MT and SC group. The short version of the PSQ consists of 20 items, with each item providing a rating on a four-point scale ranging from "almost never," "sometimes," "often" to "usually." The 20 items are assigned to the four subscales "worries," "tension," "joy," and "demands" (Fliege et al., 2009). For each scale, a mean value is calculated. After linear transformation, values range from 0 to 100. For the subscales, high values mean high "worries," "tension," "joy," and "demands." For the overall score, "joy" items are recoded and a high overall score means high perceived stress [Leibniz Institute for Psychology (ZPID), 2019].

2.7 Statistical analyses

Continuous variables are presented as mean with standard deviation (SD) or confidence intervals (CI) if evenly distributed and as median with interquartile range (IQR) if skewed.

If several cortisol probes were submitted per week by the same individual, the average cortisol value per week post-partum was calculated. Mean interindividual cortisol levels were compared by groups and 95% CIs calculated. Effect sizes were calculated according to Hedges (1981) to account for different group sizes.

To estimate the effect of music therapy on cortisol levels, multivariable regression was carried out using a linear mixed model (Supplementary material 2). Fixed effect covariates for adjustment were parents' sex (categorical) and time since birth (continuous, measured in weeks). To control for multiple measurements within one individual, a "repeated" statement was applied. The repeated statement controls the covariance matrix similar to a random effect but does not produce effect estimates like for a random effect. No interaction terms were used.

PSQ-20 subscores and the total score were calculated according to the original publication (Fliege et al., 2009). Mean subscores and the total scores were calculated with 95% CIs and Cohen's *d* calculated because the groups had equal sizes.

The interpretation of the effect sizes is based on the following values: large effects with values ≥ 0.8 , medium effects with values of 0.5 and small effects with values of 0.2 (Lakens, 2013).

Analyses were performed and figures produced with SAS Enterprise Guide 8.3 (SAS Institute, Cary, USA).

3 Results

3.1 Infants and MT sessions

Information on demographic and clinical characteristics of the infants participating in this RCT as well as on MT sessions have previously been published (Kobus et al., 2024). In brief, 100 infants (MT $n=50$, SC $n=50$), who met the inclusion criteria for this study were recruited between July 2021 and January 2023. For the analysis of parental parameters, one child of the control group had to be excluded because of early discharge. Mean gestational age was 33.4 weeks (SD 2.0) for the intervention and 31.2 (SD 3.7) for the control group. Mean birth weight was 1904.1 g (SD 479.9) for the intervention and 1604 g (SD 673.7) for the control group. There were 27 male (54%) infants in the intervention and 28 male (57%) infants in the control group. For further details please see [Supplementary Table S1](#). The music therapist performed a total of 486 music therapy sessions with a mean duration of 28.49 min (range 21–33 min). There were 45 infants receiving 10 sessions, four infants receiving eight and one infant receiving four sessions because of early discharge. MT sessions were accompanied by PC, either by close PC or hand touch.

3.2 Parental characteristics

In the MT group, 42 mothers and 8 fathers committed to accompany all MT sessions, while in the control group 43 mothers and 6 fathers participated in this RCT. Information on demographic and clinical characteristics of all participating parents are presented in [Table 1](#) (mothers) and [Table 2](#) (fathers), and on patient flow in [Figure 1](#). Mothers participated in 406 sessions and fathers in 80 sessions.

3.3 Parental salivary cortisol: differences between intervention and control group

Two mothers of the control group and one mother of the intervention group had to be excluded from the cortisol analyzes because they received the medication cortisone and prednisolone during the time the samples were collected. While in week 1 $n=25$ (21 mothers, 4 fathers) of the intervention and $n=14$ (13 mothers, 1 father) of the control group were analyzed, the return rates declined until week 4 with $n=4$ samples (3 mothers, 1 fathers) in the intervention group and increased $n=11$ samples (8 mothers, 3 fathers) in the control group. [Supplementary Table S2](#) shows how many probes (n) were analyzed in week 1–4 and the mean, minimum and maximum number of probes per participant. [Figure 2](#) depicts the course of the parental salivary cortisol levels of the intervention and control groups from week 1 to 4, with lower salivary cortisol values on each timepoint for the MT group. [Table 3](#) shows the corresponding mean cortisol levels including the 95% confidence intervals (CI) for

TABLE 1 Demographic and clinical characteristics of the included mothers.

	Intervention group ($n = 42$)	Control group ($n = 43$)
Maternal age (mean, SD)	33.6 (5.0)	33.6 (4.8)
Primipara	20 (47.6)	14 (32.6)
Multipara	22 (52.4)	29 (67.4)
Sectio caesarea	33 (78.6)	34 (79.1)
Emergency	3 (7.1)	1 (2.3)
Sec	2 (4.8)	1 (2.3)
Vaginal delivery	4 (9.5)	7 (16.3)
Nicotine abuse	2 (4.8)	0
Drug abuse	1 (2.4)	0
Pregnancy-related conditions		
Gestational diabetes	7 (16.7)	4 (9.3)
Preeclampsia	2 (4.8)	3 (7.0)
HELLP	0	0
Metabolic/endocrine disorders		
Obesity	7 (16.7)	8 (18.6)
Type 1 diabetes	1 (2.4)	2 (4.6)
Type 2 diabetes	4 (9.5)	4 (9.3)
Hypothyreosis	2 (4.8)	1 (2.3)
Medication		
Hydrocortisone	0	1 (2.3)
Prednisolone	1 (2.4)	1 (2.3)

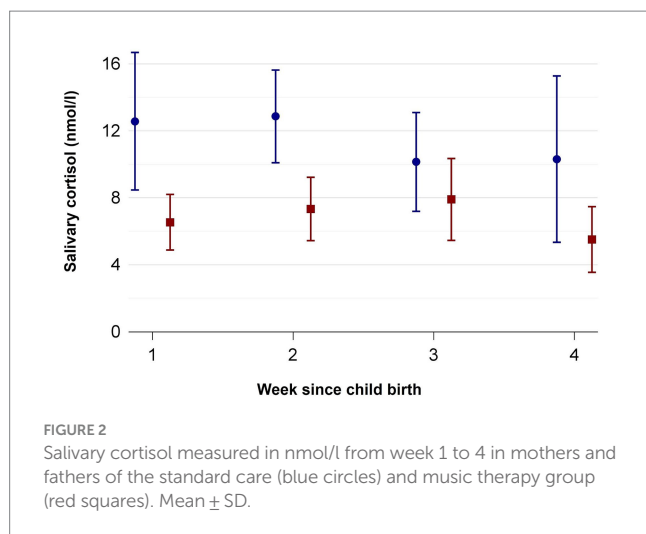
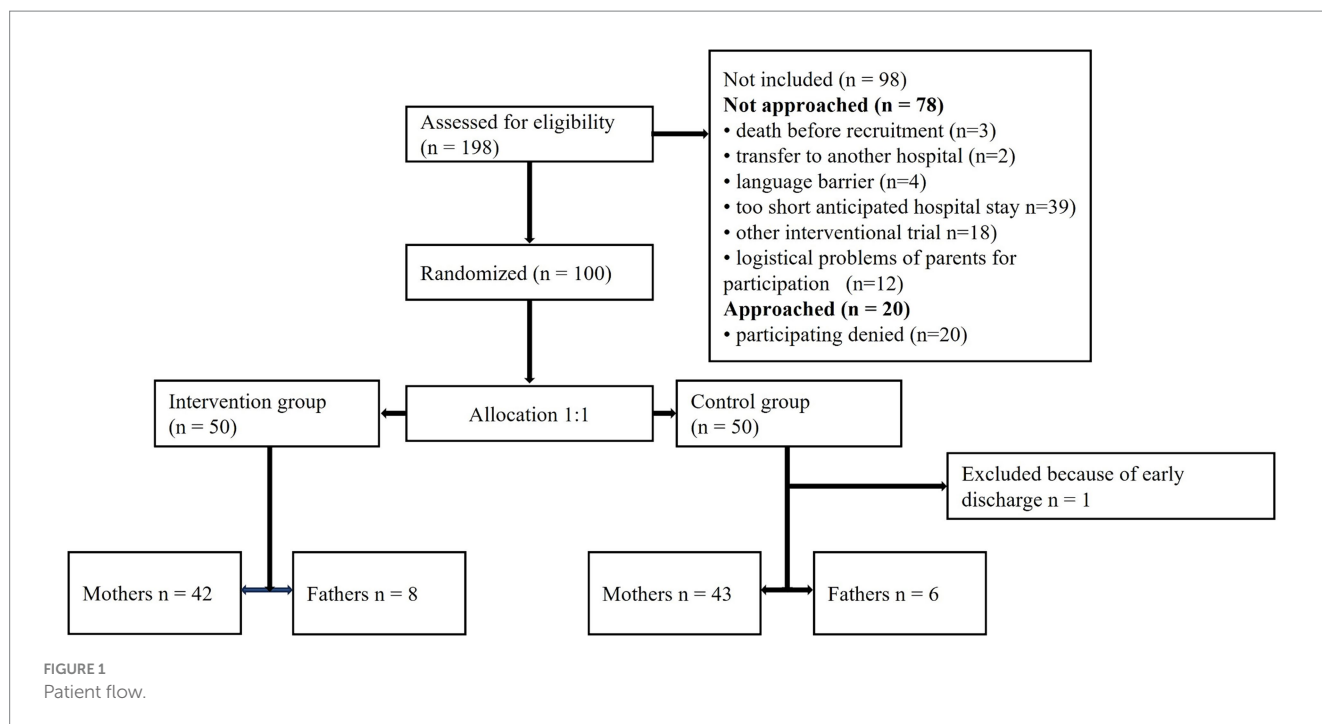
Values are depicted in mean (%), unless otherwise stated. HELLP, hemolysis, elevated liver enzymes, low platelet count.

TABLE 2 Clinical characteristics of the included fathers.

Mean	Intervention group ($n = 8$)	Control group ($n = 6$)
Paternal age (mean, SD)	35.6 (7.0)	34.7 (4.1)
First born child	5 (62.5)	4 (66.7)
Nicotine abuse	0	0
Drug abuse	0	0
Metabolic/endocrine disorders		
Obesity	0	1 (16.7)
Type 1 diabetes	1 (12.5)	2 (33.3)
Type 2 diabetes	0	0
Hypothyreosis	0	0
Medication		
Hydrocortisone	0	0
Prednisolone	0	0

Values are depicted in mean (%), unless otherwise stated.

the intervention and control group. Hedge's g effect sizes could only be determined for the mothers, because the groups of participating fathers were too small. In weeks 1, 2 and 4 the Hedge's effect sizes



indicate large effects, while in week 3 an effect size of 0.5 indicates medium effects (Lakens, 2013).

The adjusted mean cortisol levels according to multivariable regression was 6.2 nmol/l (95 CI 4.8–7.7, standard error (SE) 0.7) in the MT group versus 11.6 nmol/l (CI 9.5–13.8, SE 1.1) in the control group. The adjusted difference between the groups was 5.4 nmol/l (3.1–7.7, SE 1.1).

3.4 PSQ-20: effect of music therapy with PC on perceived stress in parents over the first 4 weeks after birth

Figure 3 presents the overall PSQ scores at birth (T1) and 4 weeks later (T2) in mothers and fathers of the intervention group (red

squares) and control group (blue circles). [Supplementary Figures S1A–D](#) differentiates the four scales of the PSQ-20, that is “worries,” “tension,” “joy,” and “demands.” A subgroup analysis for the mothers is provided in [Supplementary Figure S2](#). The backflow of questionnaires was complete for both groups at both timepoints. The corresponding statistical details on the PSQ-20 results are depicted in [Table 4](#), which includes the mean score and subscores at T1 (before recruitment) and T2 (4 weeks later) as well as the CI for the intervention and control group. Cohen’s *d* effect sizes were determined for T1 and T2. While at the time of birth, overall perceived stress as well as scores for “worries,” “tension,” “joy,” and “demands” were similar between the intervention and control group, reduced overall stress scores were measured 4 weeks later as well as reduced scores in the categories “worries,” “tension,” and “demands” for the intervention group with low effect sizes. For the control group, overall stress was higher after 4 weeks with large effect sizes.

4 Discussion

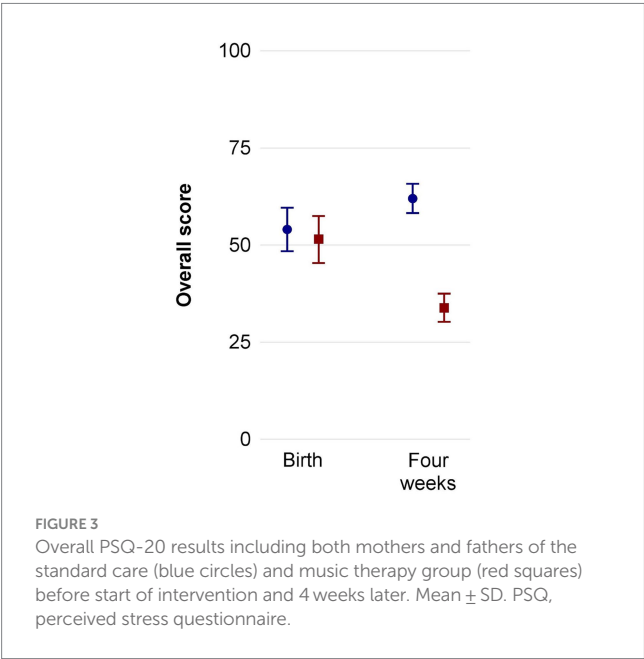
This study on the effect of live-performed MT with PC in preterm infants on parental salivary cortisol and perceived stress levels during the first 4 weeks after birth suggests decreased salivary cortisol and perceived stress levels in the MT group compared to the control group.

With cortisol as objective stress marker, this is, to the authors’ best knowledge, the first study addressing the effect of MT with PC in preterm infants on parental cortisol secretion. The hormone cortisol is used as a biochemical marker of acute and chronic stress. An increase in this hormone as an indicator of stress can be modified by psychosocial interventions like music therapy (Hasanah and Haikal, 2022). Cortisol is released by the hypothalamus-pituitary-adrenal axis in response to stress. The underlying mechanisms of music on cortisol release include the activation of brain circuits involved in pleasure and reward (Blood and Zatorre, 2001). There are connections between

TABLE 3 Parental salivary cortisol levels during the first 4 weeks after recruitment.

Timepoint	Parents	Intervention group		Control group		Effect size*
		N	Mean (nmol/l) (95% CI)	N	Mean (nmol/l) (95% CI)	
Week 1	Mother	21	6.5 (4.9–8.2)	13	12.6 (8.5–16.7)	−1.2
	Father	4	3.7 (0.7–6.6)	1	3.0	**
Week 2	Mother	21	7.3 (5.4–9.2)	15	12.9 (10.1–15.6)	−1.2
	Father	5	5.7 (0.9–10.5)	1	9.0	**
Week 3	Mother	16	7.9 (5.5–10.4)	13	10.2 (7.2–13.1)	−0.5
	Father	4	8.7 (−0.8–18.2)	2	13.4 (−55.3–82.0)	**
Week 4	Mother	7	5.5 (3.6–7.5)	7	10.3 (5.4–15.3)	−1.2
	Father	2	8.3 (7.2–9.4)	3	14.8 (8.9–20.7)	**

CI = confidence interval.
*Hedge's g, control group is considered the reference group.
**too few observations in control/intervention group.



hypothalamic nuclei and subcortical structures such as the amygdala (Hasanah and Haikal, 2022; Jensen et al., 2024). Furthermore, music might have a direct inhibiting effect on the Corticotropin-releasing factor in the hypothalamus, which are possible explanations for our results (Bowling, 2023). A salivary cortisol reducing effect of music and singing could already been shown in pregnant women, which was accompanied by improved well-being and mother-infant bonding (Wulff et al., 2021), as well as in mothers of 3–18 months old infants (Fancourt and Perkins, 2018).

Besides the reduced salivary cortisol levels, also subjectively perceived stress was reduced in the MT group compared to the control group after 4 weeks of intervention. In contrast, the perceived stress levels in the control group increased over 4 weeks, possibly due to the increasing participation of the parents in the care of their children during the NICU care, which might cause stress (Buccione et al., 2024).

The stress reducing effect of MT on parents, especially on mothers, has previously been shown by different studies (Kobus et al., 2022a;

Palazzi et al., 2021). Only few RCT addressed the effect of MT with PC in preterm infants on parental stress levels. Lai et al. showed that relaxing music (not live-performed) during close PC resulted in lower maternal anxiety compared to close PC alone (Lai et al., 2006). Teckenberg-Jansson et al. also found that dual therapy (live-performed MT and kangaroo care) was more effective in reducing parental stress than kangaroo care alone (Teckenberg-Jansson et al., 2011). A further RCT comparing MT plus skin-to-skin contact to skin-to-skin contact alone showed a non-significant tendency for greater decrease in anxiety levels as well as a trend toward a larger decrease in stress levels in the MT group (Yakobson et al., 2021).

Reducing parental stress levels during the NICU stay is important, as it improves parent-infant bonding and attachment (Ettenberger et al., 2021). A recent study found an increase in breastfeeding rates among mothers who participated in MT sessions compared to control mothers (Vianna et al., 2011). Ak et al. could show in a RCT that recorded music administered to mothers of preterm infants during breast milk expression leads to increased levels of breast milk (Ak et al., 2015). Parental stress, bonding, and breast feeding are important factors which might contribute to improved (neuro-)developmental outcomes in preterm infants (Ettenberger et al., 2021; Sullivan et al., 2023; Lapidaire et al., 2022), although a current RCT on the effect of creative MT in very preterm infants did not find differences in neurodevelopmental outcomes at 24 months corrected age between the intervention and control group (Haslbeck et al., 2023).

This study has some limitations. Due to our study design, the total time of close PC outside MT sessions was not recorded. As close PC is well established on our NICU for years, we interpreted the study results assuming that infants in the MT and control group underwent a similar amount of close PC. Although close PC alone might also reduce parental stress levels (Cong et al., 2021; Pathak et al., 2023), the reinforcing effect of combined MT with PC is suggested by the studies discussed above (Teckenberg-Jansson et al., 2011; Yakobson et al., 2021; Lai et al., 2006). A further limitation of this study is the relatively high dropout rate and differences regarding compliance between the intervention and control group. The bias in the turnover rate in favor of the intervention group may be because parents in the control group were less willing to provide cortisol samples. The drastic decrease in the number of participants providing

TABLE 4 Total PSQ-20 scores and subscores (95% confidence interval) of parents of preterm infants with and without music therapy before recruitment (T1) and 4 weeks later (T2).

	Parents	Intervention group			Effect size*	Control group			Effect size*
		N	T1 (95% CI)	T2 (95% CI)		N	T1 (95% CI)	T2 (95% CI)	
Total Score	Mother	41	51.4 (45.4–57.5)	33.8 (30.0–37.5)	–0.15	43	55.0 (48.8–61.3)	61.1 (57.0–65.2)	–2.19
	Father	9	48.7 (30.0–67.4)	36.1 (22.7–49.5)	0.10	6	46.7 (33.2–60.1)	68.1 (55.7–80.4)	–2.07
Worries	Mother	41	46.4 (39.3–53.5)	23.3 (19.0–27.7)	0.01	43	46.0 (37.0–55.0)	51.5 (45.5–57.5)	–1.72
	Father	9	47.4 (26.2–68.6)	28.1 (12.2–44.1)	0.65	6	32.2 (17.3–47.2)	55.6 (31.5–79.7)	–1.27
Tension	Mother	41	56.1 (48.6–63.7)	35.9 (31.4–40.4)	–0.18	43	61.6 (53.7–69.4)	68.5 (63.6–73.4)	–2.03
	Father	9	52.6 (32.0–73.2)	36.3 (25.4–47.2)	0.08	6	54.4 (37.6–71.2)	77.8 (65.5–90.0)	–3.12
Joy	Mother	41	55.3 (50.2–60.5)	66.7 (62.1–71.2)	0.37	43	48.2 (43.1–53.3)	44.0 (39.4–48.7)	1.69
	Father	9	59.3 (41.8–76.7)	61.5 (41.3–81.6)	0.30	6	53.3 (38.0–68.7)	40.0 (35.6–44.4)	0.77
Demands	Mother	41	58.5 (50.8–66.2)	42.8 (38.0–47.6)	–0.05	43	60.8 (52.9–68.7)	68.5 (64.2–72.8)	–1.67
	Father	9	54.1 (31.7–76.5)	41.5 (27.3–55.7)	0.03	6	53.3 (36.8–69.9)	78.9 (66.1–91.7)	–2.29

CI = confidence interval.
*Cohen's *d*.

saliva samples might also be explained by their increasing involvement in the care for their children during the NICU stay (Buccione et al., 2024). Despite the missing values, this study already shows very clear results with large effect sizes (Lakens, 2013). Larger sample sizes are needed to further investigate the effect of MT on parental cortisol levels. Additionally, the results are limited by the fact that cortisol can be influenced by several factors like sleep quality (Hirotsu et al., 2015), menstrual cycle phase (Hamidovic et al., 2020) and body weight (Brix et al., 2021). At least the prevalence of obese parents was similar between the intervention and control group. Cortisol secretion underlies a circadian rhythm, which peaks at around 8 a.m., but participants were instructed to collect saliva directly after waking up in the morning. Despite several factors influencing cortisol levels, salivary cortisol is considered the “gold standard” biomarker for chronic stress and is a valid surrogate of plasma cortisol (Levine et al., 2007; Tammayan et al., 2021). The study results are furthermore limited by the fact that stress level in parents measured with PSQ-20 and salivary cortisol, were only obtained two times and weekly, respectively, because this is an exploratory study on the effect of MT with PC on parental stress. Further time points must be investigated in future studies because stress may fluctuate during the NICU stay due to changing circumstances of the child.

5 Conclusion

The results of this study suggest that live-performed MT with PC in preterm infants leads to different parental perceived stress and salivary cortisol levels during the first 4 weeks after birth, potentially mediating beneficial effects for the infant's cognitive and socio-emotional development. Based on our recent and previous study results, the optimal setting to perform live MT might be in combination with PC. Future studies must investigate the effect of this dual strategy on the long-term development in preterm infants.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by the local Ethics Committee of the Medical Faculty of the University of Duisburg-Essen (21-9823-BO). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

MD: Writing – original draft. MA: Data curation, Writing – review & editing. TK: Data curation, Writing – review & editing. A-KD: Writing – review & editing. MS: Conceptualization, Data curation, Writing – review & editing. HE: Conceptualization, Data curation, Writing – review & editing. UF-M: Conceptualization, Writing – review & editing. NB: Conceptualization, Data curation, Formal analysis, Writing – review & editing. SK: Conceptualization, Data curation, Formal analysis, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fpsyg.2024.1441824/full#supplementary-material>

SUPPLEMENTARY FIGURE S1

PSQ-20 results for the scales "worries," "tension," "joy," and "demands" (A–D) of mothers and fathers of the standard care (blue circles) and music therapy group (red squares) before start of intervention and 4 weeks later. Mean $\pm$ SD. PSQ, perceived stress questionnaire.

SUPPLEMENTARY FIGURE S2

Overall PSQ-20 results for mothers of the standard care (blue circles) and music therapy group (red squares) before start of intervention and 4 weeks later. Mean $\pm$ SD. PSQ, perceived stress questionnaire.

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Feasibility of clinical EEG for music recognition in children aged 1–12 years

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Introduction: Musicality is an innate capability and the fundamental architectures necessary for music processing are present from birth. However, there is a notable gap in pediatric specific music neuroscience research and research that employs ecologically valid musical stimuli.

Methods: This pragmatic feasibility study aimed to assess the utility of EEG collected via pre-existing clinical monitoring to describe the processing of familiar song as an ecologically valid stimulus, in the underrepresented pediatric population. Three comparative auditory conditions (song, speech, and noise) were utilized to assess the changes in EEG across these conditions compared to a baseline silence.

Results: Analysis of EEG data from a pilot sample of four children revealed distinct changes in the underlying frequency components of the EEG during the song condition that were not observed in either the speech or noise conditions. To extend this analysis, a uniquely hypothesis-driven, multivariate statistical analysis method (generalized eigendecomposition [GED]) was employed, however in this study we did not isolate a consistent source responsible for the observed changes in the frequency components of the EEG during the song condition.

Discussion: The study is limited by the small sample size but nevertheless demonstrated feasibility of collecting EEG data in the imperfect auditory environment of an acute clinical setting to describe a response to an ecologically valid stimulus in the underrepresented pediatric population. Further research with a more restrictive study design and greater participant numbers is needed to extend these preliminary findings.

KEYWORDS

music, EEG, pediatrics, feasibility studies, GED (generalized eigendecomposition)

Feasibility of clinical EEG for music recognition in children aged 1–12 years

As a complex auditory stimulus, music consists of many components including melody, rhythm, harmony, and timbre. While these components may be processed separately, music is experienced as a rich phenomenological “whole” (1–5). Publications that objectively describe the neural processing of music overwhelmingly include adult

participants aged 18 + years (6). The brain of a child is different to that of an adult in size, shape, tissue composition, and functional connectivity (7). Further, experience dependent neuroplastic changes, and structural and functional connectivity are rapidly emerging during childhood (8). Therefore, care should be applied in translating the current music neuroscience evidence directly to children.

Engaging in music is an inherently human experience (9). Emerging neuroscience research that has explored components of the auditory evoked potential (AEP) suggests that term neonates display sensitivity to pitch, beat, duration, and tonality (10, 11). Further, functional magnetic resonance imaging (fMRI) research in neonates indicates that music stimulates a hemodynamic response throughout a bilateral network of cortical and sub-cortical regions (10, 12–15). Thus, the primary architectures of music perception appear to be present from birth. Passive musical enculturation throughout the early childhood years then results in the development of complex musical knowledge, including an implicit understanding of Western musical syntax such as the pre-conscious processing of melodic and harmonic expectations (16).

A recent systematic review describing music processing in neurotypically developing children, from term birth to 18 years, identified a significant gap in evidence in the age cohort 1–18 years (6). Twenty-three of the 46 included studies explored the neural processing of music in infants aged less than one year. This is likely because imaging occurred when the infants were in a natural sleep state. Sleep state imaging increases the quality of data by reducing movement artifacts. This control of state is difficult to implement in older infants and young children (17). Inattention and emerging language skills result in a reduced ability for infants and young children to follow instructions and remain motionless for extended periods of time. This is particularly relevant when measuring hemodynamic responses captured by fMRI which, in addition to poor temporal resolution, require the child to stay still for data acquisition with high spatial resolution (17). Electroencephalography (EEG) may therefore provide a more practical methodology to explore music processing in young children due to the high temporal resolution and tolerability for subject movement (18). Further, scalp EEG is non-invasive and the associated equipment is portable which increases the feasibility of this scanning methodology relevant to the complexities of the pediatric population (18).

Current EEG research describing components of the AEP has offered emerging insight into specific neural processes in infants and children relating to music processing and the localization of this processing. This has included sensory functions of pre-attentive auditory memory measured with the mismatch negativity (MMN) component of the AEP and more complex cognitive processing of Western music syntax measured with the early right anterior negativity (ERAN) (11, 19, 20). A significant difficulty in connecting this AEP research to developmental or clinical populations relates to the scientific reductionism employed with the use of highly deconstructed musical elements used as the auditory stimulus. For example, the mismatch negativity (MMN) utilizes an oddball paradigm to detect a

deviation in a musical element against an internal memory representation. When exploring a pitch induced MMN, the oddball paradigm typically includes the rapid and frequent presentation of a single tone “standard” with an infrequent pitch “deviant” (21). While AEP and its components are valuable for describing pre-attentive auditory and cognitive processes, they alone are insufficient to understand the neural processing of music (22). The stimuli used to measure these components of the AEP are isolated from the richer “whole” music experience that is encountered in everyday life.

The scientific reductionism of music utilized in auditory science research also reduces the ecological validity of the evidence related to therapeutic applications of music. For the purpose of this study, “whole” music is defined as music that combines the basic components of melody, harmony, timbre, and rhythm, and is organized according to the rules of Western musical syntax. Hemodynamic methods of brain imaging have successfully described brain responses to whole musical experiences in infants (13); however, as described, these methods are difficult to implement in children and necessitate data collection in foreign non-naturalistic settings. Research with adults has begun to address this gap related to the naturalistic stimulus and setting (23–25).

Pediatric specific research that explores the neural processing of a whole music is needed to expand our understanding of the developmental trajectory of music processing relevant to cortical maturation and to extend theoretical foundations and mechanistic understandings of music-based interventions for children in clinical settings (e.g., music therapy or music medicine interventions). Hence, with consideration given to the paucity of pediatric specific music neuroscience research, and the complexities of undertaking this research, the purpose of this study was twofold. Firstly, to explore the feasibility of acquiring EEG data via the pre-existing clinical equipment in an acute healthcare context that are sufficient to describe a difference in EEG response to familiar song and comparable controlled auditory stimuli, should such a difference exist. Secondly, to explore a novel method of hypothesis driven multivariate EEG analysis that considers that the generators of EEG signals responsible for processing music likely span many channels of the EEG (26). The null hypothesis addressed by this multivariate EEG analysis was: *Familiar song does not generate a unique and reproducible brain response, compared to speech, noise, and silence, as measured by EEG.*

Method

This prospective, single site study was undertaken at The Royal Children’s Hospital Melbourne (RCH) Australia. Ethics approval and governance authorisation were granted by the Human Research and Ethics Committee at RCH (HREC #74146) to recruit 10 participants. Pragmatic decisions were made to recruit children who had a clinical indication for EEG monitoring but did not present with status epilepticus or were diagnosed with a significant brain disease or disorder. The advantage of this design

was the opportunity to collect high quality EEG data via the clinical systems even within the imperfect auditory environment of an acute healthcare setting. The beneficence vs. burden of this research in children was also a significant consideration in this design because the application of EEG leads in a non-clinical population is potentially of high burden for the children and their families/guardians which likely contributes to low recruitment and underrepresentation of the pediatric cohort. The $n = 10$ was a further pragmatic decision, chosen in consultation with the Neurology Team and anticipated number of patients likely to be suitable for participation during the study period.

Convenience sampling was employed within the Neurology Department at RCH between August 2021–May 2022 of children undertaking either inpatient video-EEG monitoring or ambulatory EEG (only) monitoring.

Inclusion criteria

Inclusion criteria were intentionally broad to maximize potential recruitment. Children aged 1–12 years, who had English as their dominant language, and had non-emergency EEG monitoring at the RCH were approached for recruitment. Given the recruitment of children, participants were required to have a legally acceptable representative capable of providing informed written consent for participation.

Children who were diagnosed with a severe neurological illness or injury, or a neurodegenerative condition were excluded from participation. This included children with low functioning autism spectrum disorders, cerebral palsy, severe developmental delay, acquired brain injury, etc. Children with diagnosed hearing loss were also excluded as the experimental protocol required that the child listen to comparative auditory conditions.

Screening

Prior to recruitment to this study, the EEG of potential participants was visually assessed by the Neurology Team at RCH to observe gross abnormalities, including frequent interictal epileptiform discharges, electrographic seizures, period patterns and/or significant background abnormalities that may have impacted the collection of auditory responses. If such activity was present, the child was not approached for recruitment. Further, if EEG collected during the experimental session was visually assessed to contain frequent epileptic discharges or seizures, this data was excluded from analysis.

Data collection

Diagnostic and demographic data were collected prior to the experimental session. EEG data collection occurred within the context of continuous clinical EEG monitoring. Twenty-three leads were applied according to the standard 10/20 format. This included two additional anterior temporal leads (T1 and T2) per

the clinical protocol. Electrodes were 10 mm silver/silver chloride cup electrodes adhered with Ten20 conductive paste. Clinical EEG at RCH utilizes free lead placement instead of a cap given the improved impedance. Under the clinical protocol, all EEG leads were applied by expert EEG technicians. EEG was acquired via a Compumedics Siesta System Ambulatory Recording Device for inpatients, or Compumedics Grael V2 EEG for outpatients.

The experimental session

The experimental session was pre-recorded and consisted of the presentation of the three comparative auditory conditions: song, speech, and white noise. These auditory conditions were presented in a random order and separated by short periods of washout silence, as outlined in Figure 1. Baseline and washout periods were included in the experimental session to control for any priming and/or habituation effects of the auditory conditions. The beginning of the experimental session was indicated via an audible “click” in the recording. The randomization of the auditory conditions was undertaken by an independent statistician and assigned each participant ($n = 10$) to one of six possible permutations of the three auditory conditions. R version 4.1.0 (R Foundation for Statistical Computing, Vienna, Austria) was used to generate the randomization. The total duration of the experimental session was five minutes.

The noted paucity of EEG research exploring brain state responses to whole song in the pediatric population means there is no direct precedent for the design of the experimental session. O’Kelly et al. (27) utilized a similar protocol when describing neurophysiological responses to various music conditions in adults presenting with profoundly impaired consciousness following brain injury, however their experimental protocol was approximately 30 min in duration. The complexities of undertaking neuroscience research with children related to short attention span, poor concentration, and/or reduced ability to follow directions were considered in the research design and supported the decision to maintain a short duration for the experimental session.

The experimental session occurred in either the child’s hospital room or an outpatient EEG suite. The RCH has specifically equipped inpatient rooms for EEG monitoring which are single bed configuration, and the outpatient EEG suites are similarly specifically equipped and single seat. Single bed/seat configuration for EEG reduced the potential for extraneous noise however these rooms are not noise-attenuated and are situated in an acute hospital setting. Signs were placed on the doors to these rooms to ensure there was no unnecessary interruption during the experimental session. Auditory stimuli were presented to the participants via an mp3 player and noise cancelling headphones. The volume of each condition was adapted so that the average sound level of each condition through the headphones was approximately 60 decibels ($\pm 2\%$). Each child participated in one (1) experimental session that included the three auditory conditions presented in a random order. To control for state during the presentation of the auditory conditions, each participant watched the same silent movie on an iPad. Similarly,

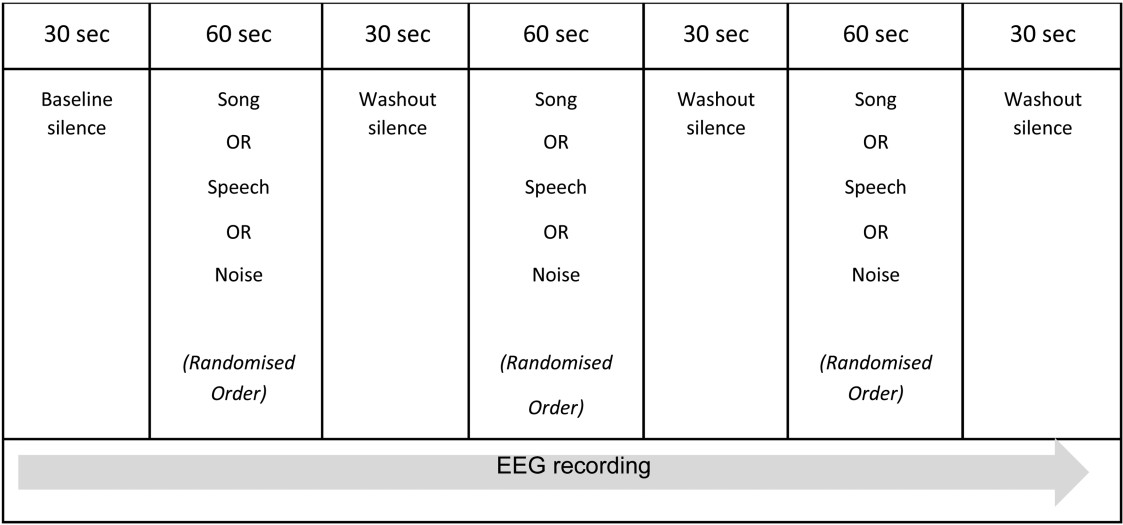


FIGURE 1
The experimental session.

recorded conditions were chosen over the live presentation of song and speech to further control state. The beginning of the experimental session (indicated via a “click” in the recording) was manually noted in the EEG via activation of an event marker to ensure temporal accuracy for data analysis.

The comparative auditory conditions presented in the experimental session were:

1. **Song.** The song condition was the pre-recorded presentation of the nursery rhyme “Twinkle Twinkle Little Star” with a simple arpeggiated acoustic guitar accompaniment. The song was sung by the first author (JB) who is an experienced music therapist, and was recorded using GarageBand Software (Apple Inc, Version 10.3.1). “Twinkle Twinkle Little Star” is a well-known Western nursery rhyme and was selected because of its cultural familiarity in the Australian context. While the song likely has different memory, emotional, social, and emotional meaning across various age cohorts, it is melodically and harmonically simple, repetitive, and follows the rules of Western musical syntax including resolution of harmonies at cadence points and thus the song was standardized across participants. The song condition had a duration of 60 s, and the song was repeated twice during this time.
2. **Speech.** The speech condition the pre-recorded speaking of the lyrics of “Twinkle Twinkle Little Star” with no musical or instrumental accompaniment. The lyrics were also spoken by the first author (JB) to control for any response to the timbre of JB’s voice. The speech condition was also recorded using GarageBand Software (Apple Inc, Version 10.3.1). The lyrics from the familiar song condition were used in the speech condition to account for any potential memory or emotional connections the participants may have to the text. The lyrics were spoken in natural speaking voice and naturally retained some elements of rhythm, vocal timbre, and prosody.

However, the speech condition did not include the wider pitch range present in the song condition, nor did it include the accompaniment of a harmonic instrument. Complete words and sentences were utilized, as opposed to the deconstructed auditory or speech stimuli, to increase the ecological validity of the condition. The lyrics were repeated three times for a total duration of 60 s.

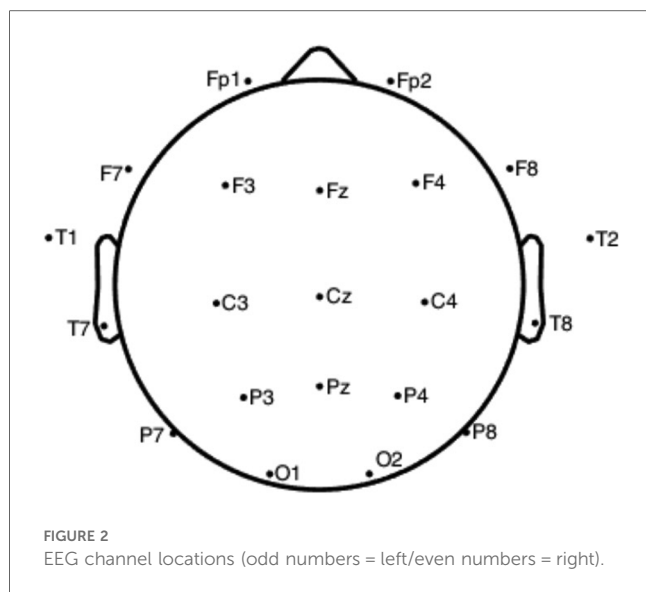
3. **Noise.** White noise was used as a non-musical, non-language, auditory control condition of 60 s.

Data analysis

Given the feasibility design of this study, all data analysis was undertaken per individual participant data. While a baseline silence was included at the beginning of the experimental session, upon inspection, this data included significant signal and external noise as the participants settled into the experimental session. Therefore, for the purpose of the following analysis, the silence data were drawn from the 30 s following the noise condition for each participant.

Pre-processing

EEG data were trimmed to 30 s per condition to align with the duration of the silence condition. The 30 s epoch was taken from the middle of each auditory condition to control for any startle or priming effect of the condition onset and to ensure temporal accuracy of any analysis. Pre-processing of the data was undertaken in EEGLAB. Data were imported and standardized to the 21 channels that were common across all participants. Channel locations are included in Figure 2. Artifact rejection was completed visually and then using Independent Component Analysis (ICA)



and independent components (ICs) of eye and muscle artifacts were then rejected. Data were then filtered utilising the FIR filter in EEGLAB with a frequency passband of 0.5–40 Hz and re-referenced to an average reference before analysis.

Time domain signal analysis

The maximum difference in each channel for each condition over the course of 30 s was calculated and visually represented. The variance in each channel for each condition over the 30 s duration was also calculated and visually represented.

Frequency analysis

Fast Fourier transform of each auditory condition was followed by inspection of the amplitudes of frequency content in the frequency spectrum. The mean amplitude for each channel across the broadband spectrum, plus the most common frequencies (delta, theta, alpha, and beta) was calculated. Frequency analysis results were represented using bar charts and topographic maps.

Analysis of variance

Generalized eigendecomposition (GED) for the song condition vs. a baseline silence was implemented to extend the analysis of the response to the song condition. GED analysis was implemented as per Cohen (26). A pre-processing step, zero-phase component analysis, was undertaken prior to GED to improve spatial sensitivity of the data. Scree plots and component topographic maps were developed for the first five components for each participant. A common critique of EEG is the poor spatial localization of responses, and the inclusion of a GED analysis supports the goal of source separation and localization of

complex cognitive tasks (for example music processing) via multivariate statistical analysis

Scalp voltage measurements reflect the spatial summation of the underlying electrical activity from the brain and the magnitudes of these voltages inherently vary over time and electrode locations. When voltage variations appear to be related in a deterministic way, they are said to co-vary, and the mutual variance between each pair of electrodes can be calculated and presented in the covariance matrix. Eigendecomposition is the mathematical analysis of this matrix to explore these relationships and draw inferences about the underlying processes.

Eigendecomposition derives a unique set of perpendicular vectors that represent the relationships between electrode pairs sorted according to variance, and an associated set of weights for the relative contribution of each vector to the covariance matrix. Eigendecomposition of a covariance matrix is the fundamental step in principal components analysis (PCA), where measured data are projected into a new coordinate system that maximize variation in the data. Generalized eigendecomposition (GED) extends this concept of sorting by variance and offers comparative analysis between exposure conditions. The difference in variance between conditions is calculated and mapped back to the original channel locations where it is assumed that greater change reflects brain involvement between conditions (26).

Results

Six children were approached, recruited, and completed participation in the experimental session ($n = 6$). Target recruitment of $n = 10$ was not achieved due to COVID-19 related reductions in non-emergency admission at RCH during the study period. The basic demographic and diagnostic information, and details of the experimental session are included in Table 1.

The data for Participants 2 and 6 was excluded from analysis. A technical error occurred with the transfer of data from the clinical system for Participant 2, and Participant 6 interacted with the iPad by playing a game during the experimental session meaning their state was not controlled. Therefore, only the data for four participants (1, 3–5) were included in the analysis. The following results of the frequency analysis include the topographic maps for the four participants of the mean amplitude of the broadband frequency range (0.5–40 Hz) in Figure 3, and the frequency analysis of the Beta range (13–30 Hz) in Figure 4.

Visual inspection of the spectral components suggests there are some changes in underlying frequency components in the song condition that are unique to this condition. Participants 1 and 5 recorded an increase energy in the EEG signal (increased mean amplitude) in the right frontal-temporal leads in both the broadband frequency range and the Beta frequency range, and this was greater than recorded in either the speech or noise conditions. This increase in energy is indicated in red in the topographic maps. Participant 3 also recorded an increase in mean amplitude during the song condition in the right frontal leads in both the broadband frequency range and the Beta frequency range, and this was greater than either the speech or

TABLE 1 Participant demographic and diagnostic data.

Participant	Age	Sex	Handedness	Diagnosis	Experimental session
1	8yr 7months	Female	Right dominant	Tuberous Sclerosis Focal Epilepsy Mild language delay	Song—Speech—Noise
2	5yrs 0months	Female	Right dominant	Left hippocampal Sclerosis Focal Epilepsy	Noise—Speech—Song
3	8yrs 11months	Male	Right dominant	Focal Epilepsy ADHD	Song—Speech—Noise
4	2yrs 9months	Female	Right dominant	? Absence seizures Nil other	Speech—Noise—Song
5	19months	Male	NA	Tuberous Sclerosis Tuber in L angular region Focal seizures	Speech—Noise—Song
6	8yrs 7months	Male	Left dominant	ASD—high functioning Epilepsy- infrequent seizures	Song—Noise—Speech

noise condition. Participant 4 recorded a paradoxical response and had a decrease in EEG signal in the fronto-central regions in both the broadband and delta frequency ranges during the song condition, compared to the speech or noise conditions. Nonetheless, in all four participants, there were changes in underlying frequency components in the song condition that were unique to that condition; that is, different to what was observed in the speech or noise conditions.

Figure 5 includes the analysis of variance (GED) for the song conditions vs. the baseline silence for each participant. Both the scree plots and component topographic maps are included. The topographic maps include the first five components for each participant, that is the components with the highest covariance. The GED analysis did not yield a response that was reproducible across all participants. That is, the mean amplitude changes recorded in the EEG signal in the broadband and Beta frequency ranges (Figures 3, 4) did not correlate with consistent topographical patterns of variance across the four participants.

Discussion

This study demonstrates the feasibility of collecting EEG data in a clinical setting that is sufficient to identify a unique response to song in children, compared to speech and noise. Despite the imperfect auditory environment of an acute hospital, power spectrum analysis revealed distinct changes in frequency components during the song condition, which were unique to that condition. Participants 1, 3, and 5 exhibited increased EEG signals within the broadband frequency range during the song condition, underscoring the potential of this data collection method to enhance our understanding of how children process music. Therefore, utilizing a pre-existing clinical EEG offers significant promise for advancing music neuroscience research in the underrepresented pediatric population.

One hundred percent of children approached were recruited for this study and completed participation in the experimental session. This type of research was arguably low burden for participants and their families, and the utilisation of pre-existing clinical EEG affords significant potential for the expansion of

knowledge with applications in real world settings. Further, the data collected via the clinical EEG system was high quality data. The independent component analysis (ICA) identified only two artifacts for removal in the EEG data: eye blink and muscle movements. These artifacts are well recognized artifacts in EEG data, and it is notable that no line noise was identified for removal. The study further supports arguments that EEG is a highly practical method of brain scanning for use with children given the high tolerance for movement (18).

The GED method of EEG analysis is a uniquely hypothesis driven multivariate statistical analysis method that has not been commonly employed in music-based neuroscience research. Spectral analysis of EEG data seeks to localize complex brain responses to single electrodes via a univariate statistical analysis; the GED method extends this analysis. Traditionally, a critique of EEG has been the relatively poor spatial localization compared to hemodynamic methods like fMRI (28). However, the GED method of EEG analysis was utilized in this study because multivariate statistical analysis increases the potential for a more statistically reliable source localization during complex cognitive tasks (26). The neural circuits involved in complex cognitive tasks, like the processing of song, are hypothesized to be combinations of functional networks of neurons that generate widespread voltage changes recorded by multiple scalp electrodes simultaneously. Thus the GED analysis considers that the signals responsible for musical processing likely span many channels of the EEG and facilitates the isolation and extraction of information across these channels (26). That is, the GED method acknowledges that it is not feasible for a one-to-one mapping of electrode to computational source and extends current uses of EEG in music neuroscience research to incorporate more complex whole music stimuli.

The implementation of the GED method of EEG analysis did not isolate a source responsible for this observed change across the participants in this study. While there was a different EEG signal recorded in the participants during the song condition, it was not possible to isolate neural generators of this response that were consistent across the participants. Based on visual inspection, the mean amplitude shown in Figures 3, 4 above did not correlate with covariance plots in Figure 5. This was not an unexpected finding given the age range of participants, the small

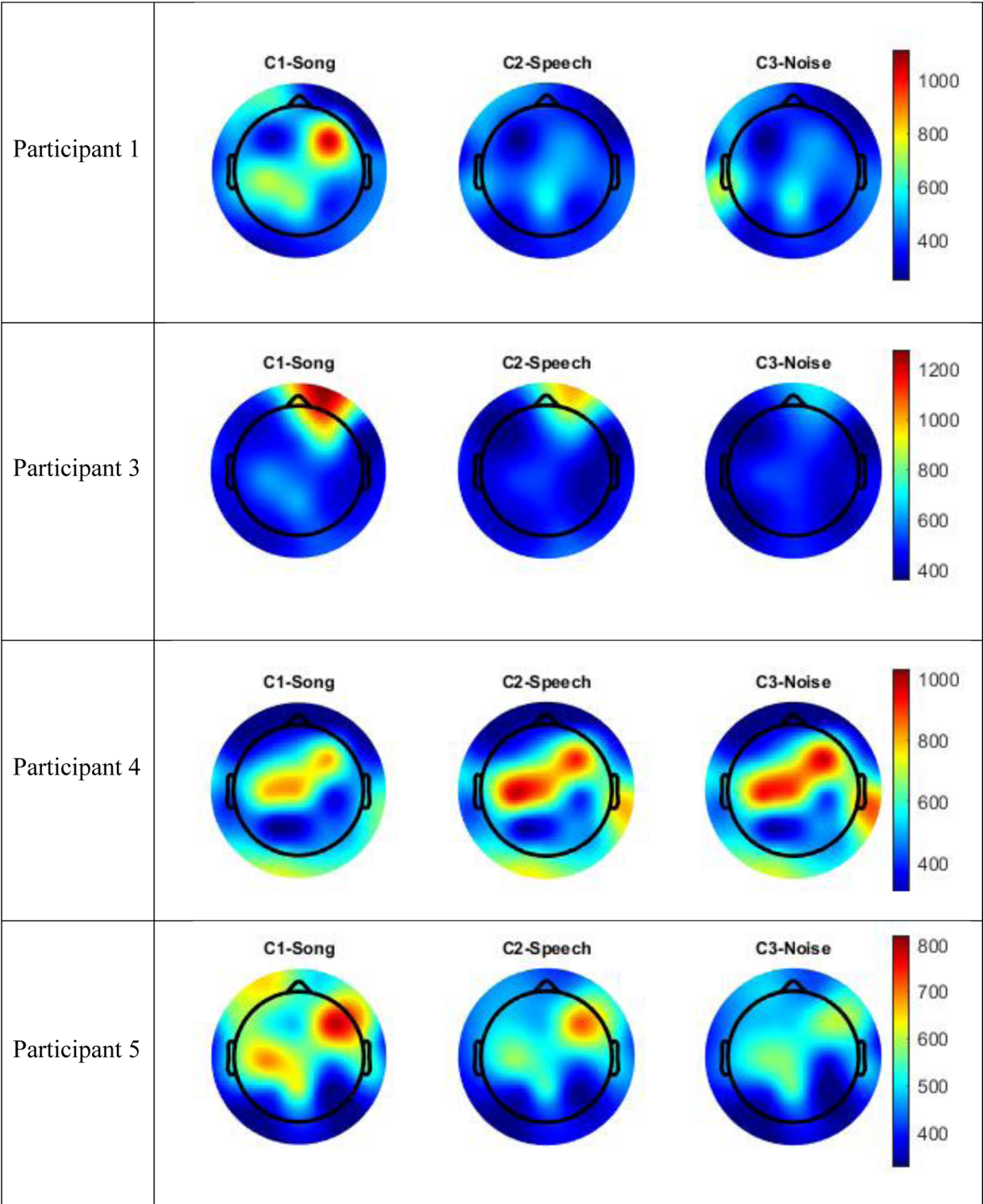


FIGURE 3
Topographic maps mean amplitude broadband frequency range (0.5–40 Hz) per condition compared to silence.

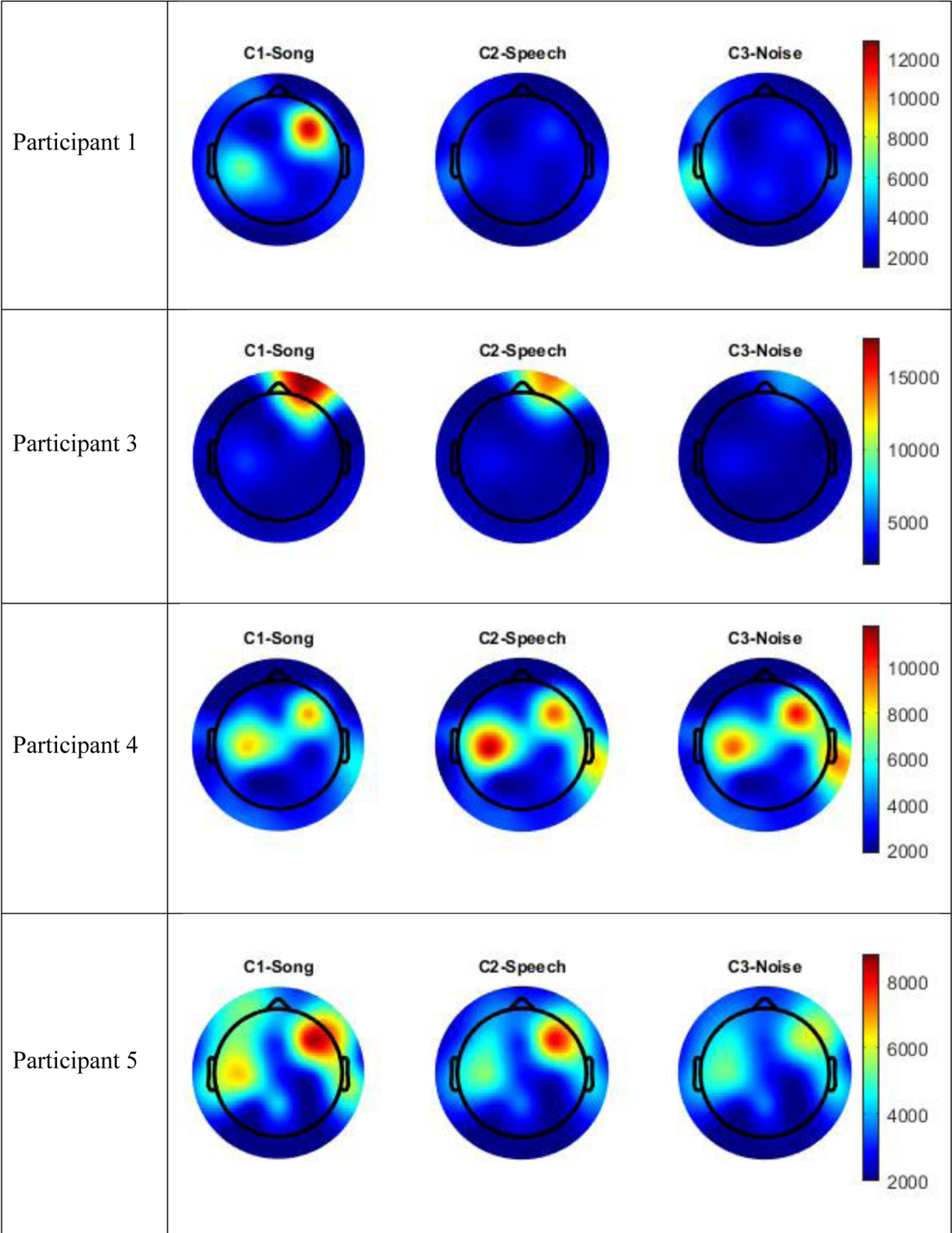


FIGURE 4
Topographic maps mean amplitude Beta frequency range (13–30 Hz) per condition compared to silence.

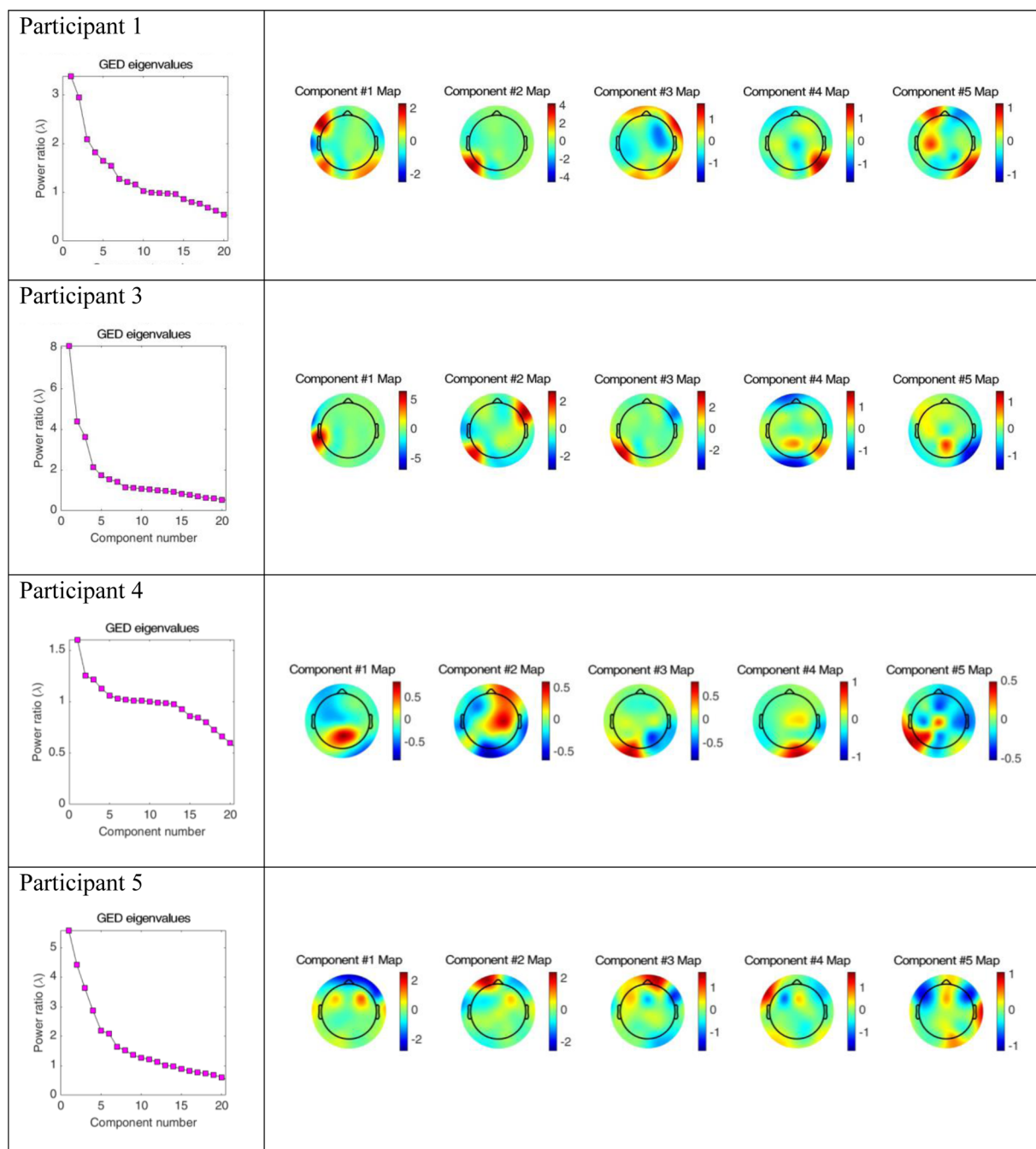


FIGURE 5

Scree plots and component topographic maps of song vs. silence for the top five components of the EEG signal for each of the four participants.

number of participants and the small number of iterations of each condition for participants. Thus, based on the data collected in this study, the null hypothesis was accepted. The acceptance of the null hypothesis in this feasibility study does not negate the potential value of the GED method in music neuroscience research, rather modifications should be made to the study design relating to data collection. Philosophically, it is also possible that increased energy on the mean amplitude topographic maps may lead to decreased co-variance. This is indicated as a cold spot on the component topographic maps due to an increase in synchronous

activity during music and the phenomena of super-position cancellation that would lead to variance tending towards zero. However, this remains purely speculative related to this study, and further research is necessary.

It is fundamental to note that the GED analysis not locating a consistent signal source across the participants is not the same as the individual participants not having a response to, or an experience of, the song condition. Rather, that each participant did record a unique EEG signal during the song condition, however, the neural generators of this response were not

consistent across the participants. It is reasonable to extrapolate that for Participants 1, 3, and 5, under the experimental conditions utilized in this study, music was a richer sensory experience that stimulated a larger brain response than either the speech or noise conditions. The localization of the increased mean amplitude to the right hemisphere aligns with current models of music processing in adults, however, a larger activation in the temporal regions may be expected based on these adult models (29). Participant 4 recorded a different response to the song condition compared to the speech or noise conditions, the response was a decrease in mean amplitude in the central and right frontal leads. Based on the data collected in this study, it is not possible to explain why Participant 4 appeared to have the opposite response to familiar song to the other three participants.

The children recruited for participation in this feasibility study all had a clinical indication for EEG monitoring with some history of seizures/suspected seizures, even if infrequently. Therefore, these participants may not have been a suitable control cohort if the intention of the study had been comparative. Arguably, this did not impact the outcomes of the study given the pragmatic intention to explore the feasibility of the clinical methodology.

The larger EEG signal recorded in three participants during the song condition also suggest significant potential for music-based interventions in clinical settings. Music may be more effective than other auditory stimuli in activating cortically mediated responses in children (30). Conversely, it is essential to consider the possibility that exposure to music in neurologically vulnerable populations may result in cognitive fatigue and overstimulation. These promising clinical applications require rigorous scientific exploration.

Study limitations

All interpretation of the results of this study should be contextualized within the feasibility design. The intention of this study was not to draw population inferences related to song processing in children or the developmental trajectory of the neural response to whole music, rather determine the feasibility of collecting data in the clinical setting that may support future statistically powered studies. The impracticalities and research burden of having neurotypical healthy children attend an acute healthcare setting solely for research purposes likely contributes to the underrepresentation of children in neuroscience research. Unfortunately, during the recruitment period for this study a pause was placed on all non-emergency hospital admissions in anticipation of an influx of COVID-19 related hospital admissions, and this further reduced the number of children who could be recruited. Given time constraints of the study, it was not possible to extend data collection.

The comparatively wide age range of the participants was a significant additional variable that resulted in limitations in the study and difficulties with generalizability of the results. All data analysis was undertaken on a single participant level and it is therefore beyond the scope of this study to explore any changes in processing across age cohorts related to brain maturation, or

to hypothesize any impact of typical or non-typical neural developmental on the processing of the song. Previous research has noted the immaturity of cortical auditory pathway in children, resulting in delayed latency and variability in the localization of components of the evoked response (31). Based on this evidence, it is reasonable to extrapolate a delayed maturation of brain response to the complex stimulus of familiar song and comparative research across various age cohorts is essential to further explore this maturation process.

Neuroscience research has the potential to support an understanding of brain processing of music, functional networks employed during music tasks, and changes in brain structure/neuroplasticity that may be stimulated by engagement in music (32). However, a limitation of traditional EEG research is that it is implausible to reduce complex musical experiences to measurable electrical activity that can be recorded at the scalp (18). While this study may have expanded current knowledge with the inclusion of a more ecologically valid music experience and multivariate statistical analysis of the EEG data, the GED method relies on multiple assumptions. These assumptions include that differences in variance reflect different brain activity related to auditory conditions (music compared to silence). It is possible that the changes might also be the result of unrelated brain states or differences in measurement noise. Future research may also seek to test GED against other multivariate statistical methods and haemodynamic methods of brain scanning to localise source generation. It also remains that music listening encapsulates the rich interplay of cognitive and emotional processing, entwined with the immeasurable cultural and social heritage of the individual child and it was beyond the scope of this study to explore this phenomenon.

Considerations for future research

Having established the feasibility of the method for its intended purpose, future research should seek to develop appropriately powered studies to track the development of responses to whole music, to developed greater knowledge of source localization. Further adjustments are also needed in future research to increase the utility of the results. Implementing a more restrictive study design may decrease the signal to noise ratio to improve the likelihood of isolating a unique and reproducible response in children. This may include controlling for potential developmental differences by recruiting to specific age cohorts (e.g., 1–2 year, 3–5 years etc), and utilising a simple novel repetitive moving graphic to offer greater control of state via visually engaging the participants without emotional content of a familiar movie.

Increasing the number of iterations of each auditory condition for participants will also reduce the signal to noise ratio of the EEG data. Experimental sessions were intentionally short in this feasibility study as acceptability of the research design had not previously been explored with children who are awake/conscious. However, future research could seek to extend this duration.

Potentially the most important consideration for future research is to increase the number of participants. Once baseline knowledge

of a unique EEG response to song and generators of this response are described in neurotypical children, the methodology could be applied to clinical populations to understand organic and non-organic (e.g., pharmacological) induced changes in music processing in clinical populations. This has the potential to support a mechanistic understanding of music-based/music therapy interventions or even support screening for developmental delays in populations where standard testing is difficult. The method of EEG data collection and analysis utilized in this study could also be extended to clinical populations where EEG is employed to describe responses to music in the absence of reliable behavioural indicators, for example children presenting with reduced consciousness.

Conclusion

EEG has enormous potential for capturing data about brain states, in real world scenarios, to increase the clinical translatability of music neuroscience knowledge for clinical applications of music within acute healthcare. This study demonstrated feasibility of collecting useful data via a pre-existing clinical system to describe the processing of an ecologically valid stimulus. Collecting data via a clinical system affords a pragmatic yet innovative opportunity to expand knowledge in the highly underrepresented pediatric population. This study design also supports the exciting potential for ongoing collaborations between clinicians and scientist to ensure knowledge is relevant and translatable to real world settings and could potentially be extended to other clinical methods of brain scanning including MRI/fMRI. The novel application of a GED analysis in this study progressed current knowledge of music processing in children beyond the time-frequency domain. This multivariate approach supports the ability to isolate and extract information that is distributed across electrodes (26). The use of a GED supports the source localization of (whole) song, as an ecologically valid music experience compared to pure tones or similarly deconstructed musical stimuli common in auditory neurosciences. While we were not able to isolate a consistent neural source of the response across the participants, data from the individual participants indicates that familiar song stimulated a unique brain response, compared to the speech or noise conditions. Further, results have potential implications for clinical applications of music because EEG may be used to describe a covert response to music in the absence of a reliable behavioural indicator. Additional research should seek to reduce variation among participants via greater recruitment and control of age cohorts and increase the iterations of the auditory conditions to decrease the signal to noise ratio.

Data availability statement

The datasets presented in this article are not readily available due to the HREC requirement for ethical approval, which is that: de-identified EEG data may be available for use

by future researchers from a recognized research institution whose proposed use of the data has been ethically reviewed and approved by an independent committee and who accept MCRI's conditions for access. Request to access the datasets should be directed to the corresponding author.

Ethics statement

The studies involving human participants were approved by Human Research & Ethics Committee, The Royal Children's Hospital Melbourne. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

JB: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. SC: Conceptualization, Data curation, Funding acquisition, Formal analysis, Software, Writing – original draft, Writing – review & editing. MW: Data curation, Formal analysis, Software, Writing – review & editing, Visualization. WM: Methodology, Supervision, Writing – original draft, Writing – review & editing. CC: Methodology, Supervision, Writing – original draft, Writing – review & editing. FB: Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Effect of an early music intervention on emotional and neurodevelopmental outcomes of preterm infants at 12 and 24 months

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Background: Few studies have found long-term effects of early musical environmental enrichment in the NICU on preterm infant's development. This study examines how early music enrichment affects emotional development and effortful control abilities in 12- and 24-month-old very preterm (VPT) infants.

Methods: One hundred nineteen newborns were recruited, including 83 VPTs and 36 full-term (FT) infants. The VPT infants were randomly assigned to the music intervention (44 VPT-Music) or control (39 VPT-control) groups. VPT-Music infants listened specifically designed music intervention from the 33rd week of gestation until hospital discharge. At 12 and 24 months, children were clinically evaluated using the Bayley-III Scales of Infant and Toddler Development and the Laboratory Temperament Assessment Battery, and at 24 months, with 3 additional episodes of the Effortful Control Battery.

Results and discussion: Our analysis showed that during a fear eliciting task, the VPT-Music group expressed lower level of fear reactivity and higher positive motor actions than VPT-controls and FT infants. At 24 months, the VPT-music group had lower scores for negative motor actions in the joy task, compared to both VPT-control and FT groups. In addition, both FT and VPT-music had higher scores of sustained attention compared to VPT-controls, but the contrasts were not significant. No significant effects on mental, language and motor outcomes were identified and for all three dimensions of the ECBQ.

Conclusion: The present study suggests that an early music intervention in the NICU might influence preterm children's emotional processing at 12 and 24 months. Limitations and suggestions for future research are highlighted.

KEYWORDS

preterm infants, music intervention, emotion, attention, effortful control

1 Introduction

Remarkable advances in obstetric management and perinatal care have substantially increased the survival rates of preterm neonates, particularly those delivered at the earliest gestational ages (Chen et al., 2016; Pierrat et al., 2017). However, this commendable increase in survival is accompanied with a range of health sequelae and neurodevelopmental challenges, including motor and cognitive impairments, as well as behavioral difficulties, spanning from early infancy to adulthood (Arpi and Ferrari, 2013; Bhutta et al., 2002; Johnson and Marlow, 2017; Montagna and Nosarti, 2016; Ritchie et al., 2015; Twilhaar et al., 2018). Notably, during childhood, a distinctive “premature behavioral phenotype” emerges, typified by cardinal features encompassing symptoms of emotional lability social problems, as well as an increased risk of presenting *attention deficit and hyperactivity disorder*, autism spectrum disorder and anxiety disorders, in comparison to full-term newborns (Treyvaud et al., 2014).

Emphasis has recently been focused on the effects of prematurity on socio-emotional development, with difficulties spanning from infancy (Clark et al., 2008; Langerock et al., 2013; Klein et al., 2013), childhood (Gardner et al., 2004; Ritchie et al., 2015; Treyvaud et al., 2013) and extending into adolescence (Healy et al., 2013).

In a meta-analysis, it has been proposed that preterm children exhibit a temperament that is less well-regulated than that of full-term infants (Cassiano et al., 2020): in fact, they exhibit a higher level of activity, a lower attentional focus compared to their full-term peer group.

Moreover, compared to their full-term peers, very premature children (VPT) (born before 32 weeks’ gestation) show increased difficulties in controlling fear and anger in the early years (Langerock et al., 2013; Lejeune et al., 2015; Witt et al., 2014), as well as difficulties in recognizing emotional content and regulating social behavior at school age (Lejeune et al., 2016).

In the study conducted by Langerock et al. (2013) forty-one VPT infants were compared with a full-term born control group utilizing a standardized behavioral assessment, the Laboratory Temperament Assessment Battery (Lab-TAB) (Goldsmith and Rothbart, 1993). This assessment aimed to measure emotional reactivity across joy, anger and fear-inducing stimuli, alongside measuring sustained attention. Analysis of emotional manifestations and emotional regulation strategies indicated that while VPT infants exhibited comparable levels of joy expression to their full-term counterparts during joy-evoking scenarios, they displayed significantly heightened reactivity in anger-provoking situations and attenuated responsiveness in fear-evoking contexts by the age of 12 months-old. Notably, across all three emotion-eliciting situations, VPT reacted with a higher level of motor activity, indicating a high level of arousal in response to stimulation. Even if longitudinal studies are needed to disentangle this specific correlation (Joseph et al., 2023), anger and attention difficulties in 12-month-old VPT infants can be early indicators of ADHD due to their critical role in emotional and cognitive development. As ADHD involves deficits in executive functions, including working memory, cognitive flexibility, and inhibitory control, infants who show early difficulties in regulating negative emotions and problems with maintaining attention, shifting focus, and processing information are considered at risk (Stephens et al., 2021). Longitudinal trajectories of emotional regulation and inhibitory capacities were investigated

(Montagna and Nosarti, 2016). Specifically, one study (Lejeune et al., 2015) was conducted using the Early Childhood Behavior Questionnaire (ECBQ) filled by parents (Putnam et al., 2006) alongside three episodes derived from the Effortful Control Battery, which evaluate two components of effortful control: delaying (waiting for a pleasant event) and inhibiting or initiating activity to signal (taking turns), respectively. VPT children were described by parents as more anxious and hypersensitive than full-term controls. This profile could be linked to later internalizing problems frequently reported in VPT children (Johnson and Marlow, 2011). Greater difficulties in maintaining inhibitory control during the effortful control tasks are also observed in VPT children (Taylor et al., 2023), especially at early school age (Réveillon et al., 2018). Witt et al. (2014) evaluated VPT children at 42 months of age with a series of specific neuropsychological tests. VPT children showed difficulties in labeling emotions and greater reactivity to fear and frustration, as well as difficulties in inhibition. These studies highlight that VPT infants exhibit heightened emotional reactivity, difficulties in inhibitory control and increased motor activity, all of which have repercussions on behavioral development and long-term social adaptation. Indeed, the early development of appropriate behavioral strategies for emotional regulation has been shown to be one of the main predictors of emotional (Berking and Wupperman, 2012), cognitive (Cisler and Olatunji, 2012) and social adaptation later in life.

The underlying alterations in brain development that lead to the high percentage of adverse outcome are not yet fully understood. However, as recent literature suggests, a major cause appears to be a combination of prenatal conditions leading to premature birth, postnatal brain injury, particularly white matter injury and impaired brain maturation (Inder et al., 2023; Miller et al., 2005; Volpe, 2019). It has been well demonstrated that the brain develops during the first 6 months of fetal life mainly under the influence of genetic influences, which are then replaced by intra-uterine environmental factors or external factors in the neonatal intensive care units (with related stressful events) that can alter the typical development of brain structures, leading to subsequent functional consequences (Cheong et al., 2020; Lammertink et al., 2021; McGowan and Vohr, 2019; Vasung et al., 2019). Indeed, premature birth generally entails a radical change of environment for the infant depriving him or her of the expected intra-uterine factors and exposing him or her to a variety of stressful sensory stimuli and procedures in hospital wards: equipment, pain, mobilization, noise. Parents of children born prematurely are also exposed to high levels of stress, anxiety and depression (Treyvaud et al., 2014). These multifaceted factors collectively shape maternal sensitivity and responsiveness during interactions with their infants, thereby exerting a profound impact on the child’s developmental trajectory (Forcada-Guex et al., 2011), with enduring ramifications for their socio-emotional competencies (Turpin et al., 2019).

In recent decades, research has provided a better understanding of the complex relationships existing between the environment and brain development (Tooley et al., 2021). Early preventive interventions are usually implemented during the hospitalization in the NICU, with the aim of optimizing brain plasticity, creating and maintaining adequate neuronal connections. These interventions are designed to support the development of the very vulnerable premature infants and allowing them to develop stress regulation capacities (Kuhn et al., 2018; Symington and Pinelli, 2006; Westrup, 2016). More recently, various studies have been carried out on different types of multisensory

enrichment during hospitalization to optimize the infant's sensory experience and thus potentially improve development.

Early music interventions, particularly those centered on neonatal care, have been a subject of consistent inquiry, with research focusing on the immediate advantageous impacts of music listening and music therapy during the neonatal period.

Music listening involves exposure to recorded music, during which infants demonstrate receptiveness to a standard musical stimulus. A music therapy intervention consists of a systematic, interactive approach conducted by a qualified therapist, frequently utilizing live music to achieve designated therapeutic objectives.

In the NICU, music listening entails subjecting premature infants to standardized recorded music. Studies indicate that newborns are responsive to recorded auditory stimuli. Conversely, music therapy is a systematic and participatory intervention conducted by a qualified music therapist. It generally incorporates live music and is customized to address the individual requirements of each newborn. This interactive method fosters a dynamic and responsive treatment setting, potentially enhancing the efficacy of addressing the specific requirements of preterm newborns (Yue et al., 2021; Haslbeck, 2012).

A number of existing reviews and meta-analyses undertook the assessment of the impact stemming from early music and music therapy interventions on preterm infants within the NICU (Bieleninik et al., 2016; Haslbeck, 2012; Haslbeck et al., 2023; Palazzi et al., 2018; Van der Heijden et al., 2016; Yue et al., 2021). More specifically, evidence emerged on the impact of an early musical enrichment of the NICU environment on the structural and functional development of the premature infant's brain (de Almeida et al., 2023; Loukas et al., 2022; de Almeida et al., 2020; Lordier et al., 2019a; Lordier et al., 2019b). However, the current body of research predominantly focuses on the immediate effects of music and music therapy during the neonatal period, creating a critical gap in our understanding of the enduring and sustained benefits or potential challenges that may arise over an extended period beyond the NICU stay.

While the aforementioned reviews offer valuable insights into the limited short-term effects of music and music therapy on preterm infants, particularly in areas such as heart rate, respiratory rates, feeding domains and parental anxiety, a more comprehensive understanding of their impact requires future investigations that extend their scope to encompass the long-term developmental trajectory of these infants, including their later emotional processing (Beltrán et al., 2022; Haslbeck et al., 2023). Addressing this research gap is essential for refining the efficacy of early music and music therapy interventions and informing holistic care strategies for preterm infants throughout their development.

The present study aims to comprehensively assess the impact of an early environmental enrichment through music during hospitalization on various facets of development, specifically focusing on temperament—including emotional abilities and attentional capacity, and effortful control abilities in a cohort of very VPT infants at 12-months and 24-months old, by comparing them to a control group of VPT infants and a group of full-term infants.

2 Method

2.1 Population

The original sample comprised 105 VPT (with a gestational age at birth of less than 32 weeks) and 48 infants born full-term (FT). These

infants were part of a longitudinal study examining the impact of early music exposure during their stay in the NICU, as outlined in the studies by Lordier et al. (2019a,b) and de Almeida et al. (2023) on brain processing and neurobehavioral development. Recruitment took place at the University Hospital of Geneva, with written informed consent from the parents obtained before the participation of each newborn. The study adhered to the principles of the Declaration of Helsinki and received approval from the ethics committee at the University Hospital of Geneva. VPT were randomly allocated to either musical intervention group (55 VPT-music), or no-music intervention group (50 VPT-control).

The present study involved a comprehensive assessment of the motor, cognitive, language and emotional abilities of children aged 12 and 24 months, conducted within the follow-up unit of the University Hospital of Geneva. Three participants from the original cohort were excluded from the follow-up assessment. Exclusion criteria for all neonates included the presence of major brain lesions identified on early MRI, such as intraventricular hemorrhage grade III with or without apparent periventricular hemorrhagic infarction, or cystic periventricular leukomalacia (1 FT, 1 VPT-control) and genetic syndrome (1 VPT-music). Thirty-one infants did not participate to the follow-up due to parent refusal (5FT, 4 VPT-music, 6 VPT-control), move to another city/country (1FT, 6 VPT-music, 1 VPT-control), or because the parents were unreachable (5FT, 3 VPT-control). The neonatal characteristics of VPT infants who participated in the follow-up at 12 and 24 months compared with those who were lost to follow-up were not significantly different, in terms of sex, gestational age at birth, birth weight, and presence of bronchopulmonary dysplasia or sepsis. However, lower socioeconomic scores (meaning higher socioeconomic status; $p=0.026$) of the children lost to follow-up (mean: 3.895 ± 1.969) was observed when compared to those who attended follow-up (mean: 5.215 ± 3.189).

The final sample included 36 FT, 44 VPT-music (age range at birth, between 24 and 31.9 weeks of gestational age), and 39 VPT-control (age range at birth, between 24 and 32.57 weeks of gestational age, for details see Figure 1). At 12 months of corrected age, data were collected for 28 FT, 42 VPT-music and 33 VPT-control and at the corrected age of 24 months, information was gathered for 30 FT, 29 VPT-music and 25 VPT-control (for details see Figure 1).

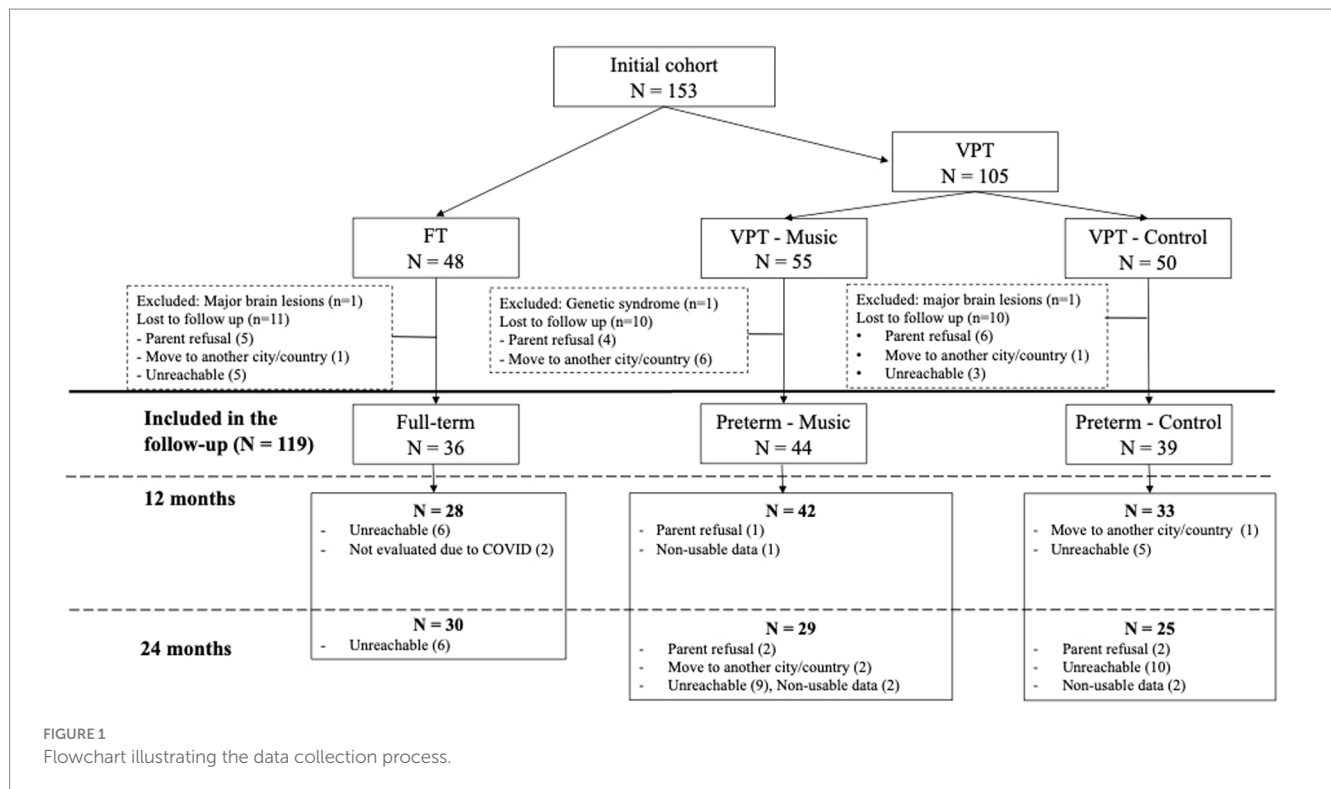
2.2 Study design

2.2.1 Intervention

Parents, caregivers, and providers of music intervention were blind to the group assignment.

The newborns in the control group were provided with headphones that were identical to those given to the neonates in the experimental group. However, it should be noted that these headphones were non-functional. Consequently, when the experimenter placed the headphones, it was impossible to ascertain if the infant was truly being exposed to the music or not. Using headphones, the VPT-music group listened to 8-min infant state adapted music extracts composed by Andreas Vollenweider,¹

¹ <http://vollenweider.com/en>



beginning at 33 weeks' gestation and continuing until hospital discharge or term-equivalent age.

The infant was exposed to music in accordance with his biological rhythm and state of wakefulness: one composition was designed to assist the infant in awakening, another to sustain the infant in a state of tranquil awakening, and the final one to facilitate the infant's descent into sleep.

To accommodate the infants' states of wakefulness, the structures of the three pieces of music were different. The music designed to help the baby wake up started with a soothing background, with instruments gradually being introduced. Conversely, the music intended to help the baby fall asleep began with instruments, which were then gradually removed. For the music administered during the active state, instruments were evenly distributed throughout the piece. The auditory spectrum and the musical pieces can be found in our previously published paper (Lordier et al., 2019b).

The three pieces are stereophonic musical excerpts in B major, lasting 8 min each, composed by Andreas Wollenweider. The main foundation of the three pieces is a sound bed that features a multitude of harmonics originating from human voices. Musical elements such as harp, punji, and bells intermittently punctuate this vocal tapestry at various points within the stereophonic panorama.

The musical pieces utilize a tempo moderato and a steady rhythm that provide a consistent auditory experience. The harmonics from the human voices create a rich and layered sound bed, which serves as the primary backdrop of the composition. This vocal foundation is dynamically enriched with the occasional introduction of instrumental sounds. The first instruments that is gradually introduced in the musical piece is the harp. The delicate plucking of the harp strings adds a gentle quality to the music, enhancing the overall texture and providing melodic highlights. Secondly, the principal melody has been presented by the punji, a traditional wind instrument, introducing

unique timbres and cultural flavors, contributing to the piece's diversity. Six simple melodies played by the punji were repeated throughout the music extract. The mean pitch of the melodic lines played by the punji is 319.2 Hz (range 320–360 Hz). Finally, the sporadic chimes of bells offer a percussive element that punctuates the soundscape, creating moments of clarity and accentuating the harmonic richness.

The three pieces present the same structure (Background + instrumental sounds), the same rhythm and tempo characteristics, they are in the same key, they only differ for the presentation of the instrumental sounds.

The music designed to help the baby wake up started with a soothing background, with instruments gradually being introduced. It presents a moderate crescendo in intensity in the central part. Conversely, the music intended to help the baby fall asleep began with instruments, which were then gradually removed and in the central part a moderate diminuendo gradually leads to the end of the piece. For the music administered during the active state, instruments were evenly distributed throughout the piece. The music extracts are presented in Lordier et al. (2019b) in the Supplementary material.

The infant's readiness for music exposure and the appropriate track were determined using a neonatal behavioral assessment scale (Martinet et al., 2013).

The grid extensively describes the infant's behavioral and physiological characteristics in the different sleep and awake states, guiding the nurses in observing the child's behavior and physiology, including heart and respiratory rates, signs of discomfort, and self-regulation. All the nurses involved in the project were trained to the grid use. The music was not administered when the babies were in a deep sleep state or a crying state. After nutrition time, if the newborns were falling asleep, dedicated music for the sleep state was chosen. Before care

procedures or nutrition times, when the baby was in an active sleep state and beginning to transition to the awake state, the third piece of music, designed for the sleep-to-awake state, was administered.

The intervention was exclusively executed in the infant's crib. The sound level varied from 30 dBA (background) to 65 dBA (peak with the bells). More details about the music intervention can be found in Lordier et al. (2019).

VPT-music infants listened to music about 5 times per week and VPT-control infants had open headphones put on without music at the same frequency. Infants were presented with a music piece approximately 2 times per day, so a mean of 16 min per day.

The mean number of music experience was 46.76 (SD = 24.70) for the VPT-music group and the mean number of times having the open headphones was 43.5 (SD = 26.73) for the VPT-control group ($p = 0.57$). Headphones were specifically designed for the study and adapted to preterm infants' head size (for a detailed description of the headphones including pictures, see Supplementary Figure S2 in de Almeida et al., 2023).

A cohort of FT infants was enrolled at the maternity unit of the hospital in their first days of life. They were subsequently contacted at 12 and 24 months for follow-up evaluations.

2.2.2 Perinatal characteristics

Characteristics such as sex, gestational age, birth weight, presence of bronchopulmonary dysplasia or sepsis, were obtained from the birth record and are presented in Table 1.

The socioeconomic status (SES) of the families was calculated using the Largo et al. (1989) questionnaire. The SES was computed on a 12-point scale, considering both paternal occupation and maternal education, with scores ranging from 2 (indicating the highest SES) to 12 (representing the lowest SES).

2.2.3 Cognitive, language, motor, and emotional assessment

Parents gave written consent for participation in the study and video recording of the assessment. Each child, in the presence of a caregiver, was assessed in a quiet room. Items were administered and scored by qualified psychologists and psychomotor therapist blinded to group assignment.

At 12 months of age (or corrected age for children born prematurely), cognitive, language and motor development were assessed using the Bayley scales of infant and toddler development third edition (Bayley-III) (Bayley, 2006). Four items from the laboratory temperament assessment battery (Lab-TAB), described in the paragraph on measures, were used to observe individual differences in emotional expression (fear, anger, joy), activity level (sustained attention) and regulatory aspects of behavior (Goldsmith and Rothbart, 1999). The child's temperament was also assessed using the Infant Behavior Questionnaire (IBQ) (Rothbart, 1981).

At 24 months (or corrected age for children born prematurely), the children were also assessed using the Bayley-III and Lab-TAB. In addition, the ability to inhibit a motor response and delay gratification were assessed with 3 episodes of the Effortful Control Battery (ECB) (Kochanska et al., 2000). Parents also completed the short version of the Early Childhood Behavior Questionnaire (ECBQ) (Putnam and Rothbart, 2006).

2.3 Behavioral, emotional and neurodevelopmental measures

2.3.1 Laboratory temperament assessment battery (Lab-TAB)

The 4 episodes of the Lab-TAB, a reliable and valid observation protocol, were the puppet game (assessing expressions of joy), the attractive toy placed behind a barrier (assessing expressions of anger), the unpredictable mechanical toy (to evaluate fear responses), and the blocks (to rate sustained attention). Lab-TAB coding involved facial, vocal, and bodily measures. For each episode, measures were derived from the LAB-TAB coding manual and coded on a scale from 0 to 3, with 3 indicating a stronger emotional response. Each emotion involves specific activation of different facial regions (Izard et al., 1983; Izard and Malatesta, 1987). Thus, coding facial intensity for anger and fear is based on the number of facial regions activated (e.g., a score of 3 is assigned if 3 specific emotion-related regions are activated). Coding details are in the Lab-TAB manual.

The puppet game assesses joy and involves the presentation of a scripted puppet show, lasting around 1 min, which tickles the child three times. Scoring was carried out for four equivalent time intervals

TABLE 1 Population characteristics.

	VPT-control	VPT-music	Full-term	VPT-control vs. VPT-music
	<i>n</i> = 39	<i>n</i> = 44	<i>n</i> = 36	
	<i>n</i> (%) or mean(<i>SD</i>)	<i>n</i> (%) or mean(<i>SD</i>)	<i>n</i> (%) or mean(<i>SD</i>)	<i>p</i> -value ^a
Sex, number of females	22(56%)	20(45%)	21(58%)	ns 0.45
Gestational age at birth (weeks)	28.91(2.2)	28.78(2.2)	39.43(1.1)	ns 0.763
Birth weight (g)	1,147(303)	1,181(419)	3,261(407)	ns 0.888
Bronchopulmonary dysplasia	13(33%)	16(37%)	0	ns 0.773
Early and late onset sepsis	12(31%)	7(16%)	0	ns 0.108
Socioeconomic score ^b	5.33(3.4)	5.10(3.2)	4.14(2.9)	ns 0.791

^aPearson's chi-square and Mann-Whitney U-tests were used for the comparison of the variables between the VPT-music, VPT-control groups.

^bThe socioeconomic status (SES) was calculated using the Largo et al. (1989) 12-point scale based on paternal occupation and maternal education (range from 2 – the highest SES – to 12 – the lowest SES).

(introduction, first tickle, second tickle and third tickle). A mean score of joy (smile intensity; positive vocalizations, for example babbling or squealing; touching puppets rate) was made. The intensity of negative motor activity was also coded (for example, continuous and brutal pushing away of the puppets was scored as 3). To assess anger, an attractive toy was presented to the child, then gently taken from his hands and placed behind a plexiglass barrier for 30 s. The task was repeated twice. Anger intensity (vocal, for example full intensity cry or scream was scored as 3; facial; and motor) was rated in 5-s intervals and averaged for each trial. An average anger score for each trial and for the entire task was calculated. Fear is assessed by a task with an unpredictable mechanical robot that moves toward the child, stops in front of him and makes grunts, then moves back. The episode lasted 15 s and was repeated twice. The mean of fear ratings (facial; vocal, for example mild vocalization that may be difficult to identify as hedonically negative was coded as 1; and bodily, for example visible and sustained tensing of the muscles, associated with decreased activity was coded as 2) was calculated for each trial. Positive motor actions (approaching the robot and trying to grasp it) were also rated for each trial. A mean score for fear and a mean score for positive motor action throughout the task were calculated. The Blocks episode measures the child's sustained attention in free play with blocks for 3 min. Facial interest, gaze duration and object manipulation duration were scored in 10-s time intervals. All scores were averaged to calculate a sustained attention score for each minute and an average score for the 3 min.

2.3.2 Effortful control battery

The 3 episodes of the Effortful Control Battery were Snack delay, Wrapped gift and Tower. The Snack Delay measures the child's ability to delay gratification. The child must keep their hands on the table and not touch or eat the treat placed in front of them before the experimenter rings the bell. This task was presented 4 times, with delays of 10, 20, 30 and 15 s. In the middle of each trial, the experimenter lifted the bell but did not ring it. For each trial, an inhibition score was calculated on a scale of 1 to 9 (1 = the child ate a snack before the experimenter raised the bell; 7 = the child waited for the bell to ring). An extra point was awarded if the child kept his hands on the table at least half the time, and 2 points if he kept them there throughout the trial. An average inhibition score across the 4 trials was calculated. The Wrapped Gift also measures the child's ability to delay gratification. The experimenter tells the child that he has a gift for him but has forgotten to wrap it. The child must wait with his back facing the experimenter and not look at the experimenter when he wraps the gift (60 s). The child thus obtains a score from 1 to 5 for turning to look at the gift wrapping: 1 = the child turns and continues to look; 3 = the child looks over his shoulder; 5 = the child does not look. Next, the wrapped gift is placed on the table and the experimenter leaves the room, telling the child not to touch the gift until he returns (180 s). The child obtains a score from 1 to 4: 1 = the child opens the gift; 4 = the child never touches the gift. The Tower assesses the ability to wait one's turn by suppressing an impulsive motor response. The child must take turns building a tower with the experimenter. A first attempt is made to ensure that the child has understood the task. The episode comprised 2 trials, and an inhibition score was calculated for each trial. The total number of blocks placed (multiplied by 10) was divided by the number of blocks placed by the child. The maximum score (20) was obtained if the child waited his turn. A penalty of -5 points was

applied if the child intentionally knocked over the tower. An average inhibition score combining the two trials was also calculated. Effortful Control examines the child's ability to regulate attention and inhibit impulses, reflecting self-control and attentional focus. Negative Affectivity explores the extent to which the child displays negative emotions, such as anger, frustration, or fear. Surgency-Extraversion delves into traits related to positive anticipation, sociability, and approach behaviors, reflecting the child's level of extroversion and enthusiasm in social interactions. These three subscales collectively contribute to a nuanced understanding of a child's behavioral tendencies and emotional responses during early childhood.

2.3.3 The infant behavior questionnaire (IBQ)

The questionnaire comprises 191 questions to which the parent answers from 1 (never) to 7 (always), and evaluated six domains of infant temperament, encompassing activity level, soothability, fear, distress in response to limitations, smiling and laughter, and the duration of orienting. Parents were asked to rate the frequency of temperament-related behaviors observed in their infants over the preceding week. Three subscales were utilized in the assessment, encompassing Surgency/Extraversion, Negative Affectivity, and Orienting Regulation. Surgency/Extraversion explores traits related to positive anticipation, sociability, and approach behaviors. Negative Affectivity delves into aspects associated with distress, fear, and frustration. Orienting Regulation focuses on the child's ability to attend to and engage with environmental stimuli. These subscales collectively provide a comprehensive understanding of the infant's temperament across different dimensions.

Not all the parents completed the extensive questionnaires, and the numbers of missing questionnaires was reported in [Tables 2, 3](#). If a caregiver omitted an item, or if the caregiver checked the "Does not apply" response option for an item, the item receives no numerical score and is not factored into the scale score.

2.3.4 Early childhood behavior questionnaire (ECBQ)

It includes 107 questions, with responses ranging from 1 (never) to 7 (always), and provides scores for: Activity Level, Attentional Focusing, Attentional Shifting, Cuddliness, Discomfort (amount of negative affect related to sensory qualities of light, sound, texture stimulations), Fear, Frustration, Low-intensity and High-intensity Pleasure, Impulsivity, Inhibitory Control, Motor Activation (i.e., repetitive small-motor movements), Perceptual Sensitivity, Positive Anticipation, Sadness, Shyness, Sociability, Soothability. Three subscales of the ECBQ offer insights into distinct aspects of a child's temperament.

2.4 Data analysis

All statistical analyses were conducted using SPSS 27.0 (IBM SPSS Statistics, IBM Corporation).

To test for differences in demographic and perinatal data between groups, categorical variables were analyzed using chi-squared test, whereas continuous variables were compared using Mann-Whitney U-tests.

Analyses of covariance (ANCOVA) were used, with SES as a covariate (after controlling the insignificance of the relationship

TABLE 2 Results of assessment at 12 months in the 3 groups.

	VPT-control	VPT-music	Full-term		
	mean(SD)	mean(SD)	mean(SD)	F	p
Bayley scales	(n = 33)	(n = 42)	(n = 11)		
Cognitive	102.73(12.6)	101.55(10.8)	110.00(11.3)	1.84	0.166
Language	92.00(8.6)a	93.43(8.2)a	99.73(5.9)b	3.51	0.035
Motor	93.33(10.2)a	93.26(8.8)a	105.73(9.8)b	7.12	0.001
Lab-TAB	(n = 32)	(n = 41)	(n = 28)		
Puppet game					
Joy	0.86(0.54)	0.99(0.59)	0.81(0.49)	0.059	0.594
Negative motor action	0.50(0.41)	0.38(0.44)	0.40(0.54)	0.722	0.597
Toy behind barrier					
Anger-Trial 1	0.81(0.61)	0.65(0.61)	0.61(0.51)	1,987	0.143
Anger-Trial 2	0.64(0.46)	0.76(0.55)	0.68(0.50)	0.639	0.530
Anger (mean)	0.79(0.63)	0.75(0.58)	0.64(0.47)	1,525	0.223
Distraction-Trial 1	1.09(0.90)	1.12(0.83)	0.76(0.67)	0.575	0.565
Distraction-Trial 2	1.42(0.99)	1.27(0.92)	1.03(0.86)	0.524	0.594
Distraction (mean)	1.26(0.88)	1.22(0.76)	0.91(0.67)	0.518	0.597
Unpredictable toy					
Fear-Trial 1	0.32(0.27)	0.26(0.31)	0.37(0.28)	1,844	0.164
Fear-Trial 2	0.30(0.28)a	0.22(0.29)b	0.54(0.37)c	10.09	0.001
Fear-Trial (mean)	0.31(0.22)a	0.25(0.30)a	0.44(0.31)b	5,162	0.007
Positive motor action-Trial 1	1.20(0.94)a	1.63(0.97)b	1.04(0.88)c	3,891	0.024
Positive motor action-Trial 2	1.31(1.04)a	1.62(1.08)b	0.98(1.02)c	3,235	0.044
Positive motor action (mean)	1.29(0.90)a	1.65(0.99)b	1.02(0.88)c	4,311	0.016
Blocks					
Sustained attention- Trial 1	2.58(0.47)	2.56(0.40)	2.41(0.58)	0.111	0.111
Sustained attention -Trial 2	2.21(0.87)	2.33*(0.62)	2.34(0.58)	0.591	0.591
Sustained attention-Trial 3	1.99(0.90)	2.20(0.76)	2.05(0.69)	0.555	0.555
Sustained attention (mean)	2.25(0.67)	2.36(0.49)	2.28(0.53)	0.463	0.463
IBQ	(n = 17)	(n = 34)	(n = 29)		
Extraversion	4.80(0.72)	5.11(0.57)	4.92(0.49)	0.098	0.143
Negative affectivity	3.96(0.50)	3.97(0.56)	4.24(0.44)	0.143	0.530
Orienting regulation	4.66(0.58)	4.85(0.59)	4.69(0.46)	0.373	0.223

Boldface entries indicate significant difference ($p < 0.05$); a,b,c: different letters significant difference at $p < 0.05$.

between SES and Group and the equality of slope of regression lines in the three groups). Analyses of covariance were performed for each dependent variable comparing the three groups (VPT-music vs. VPT-control vs. full-term) as between-subjects factor, with sex as additional between factor and SES as a covariate. The analyses were conducted separately for measures at 12 and 24 months.

Effect sizes and observed power for the overall ANCOVAs were reported, as well as post-hoc contrasts. The significant threshold was ≤ 0.05 and the marginal threshold was ≤ 0.07 . In addition, we calculated the post-hoc achieved power with G*power 3.1, providing the given alpha level, effect size set as large, and actual sample size. The calculated achieved power is 0.97, which is considered adequate.

3 Results

No significant differences were found between the three groups (VPT-music, VPT-control and full-term) regarding the neonatal characteristics and the SES.

3.1 At 12 months

Table 2 presents the findings of the clinical assessment of children at 12 months corrected age.

No significant effect of the music intervention on Bayley-III scales, was observed at 12 months. For Language scores, there was a

TABLE 3 Results of assessment at 24 months in the three groups.

	VPT-control	VPT-music	Full-term		
	mean(SD)	mean(SD)	mean(SD)	<i>F</i>	<i>p</i>
Bayley scales	(<i>n</i> = 23)	(<i>n</i> = 31)	(<i>n</i> = 30)		
Cognitive	98.26(9.24)	97.58(11.47)	103.0(10.05)	1,369	0.261
Language	90.52(9.43)	89.48(11.14)	94.53(10.43)	0.957	0.388
Motor	96.30(8.64)	96.45(10.81)	102.0(12.26)	1,958	0.148
Lab-TAB	(<i>n</i> = 22)	(<i>n</i> = 27)	(<i>n</i> = 31)		
Puppet game					
Joy	0.98(0.68)	1.02(0.63)	0.85(0.54)	1,209	0.304
Negative motor action	0.55(0.53)a	0.16(0.27)b	0.49(0.59)a	4,729	0.012
Toy behind barrier					
Anger-Trial 1	0.44(0.33)	0.68(0.70)	0.63(0.40)	0.879	0.420
Anger-Trial 2	0.41(0.37)	0.62(0.72)	0.71(0.53)	0.562	0.456
Anger (mean)	0.43(0.31)	0.63(0.69)	0.66(0.43)	0.921	0.403
Distraction-Trial 1	0.80(0.84)	0.80(0.85)	0.66(0.96)	0.144	0.866
Distraction-Trial 2	1.21(1.0)	1.10(1.2)	0.79(0.98)	0.681	0.509
Distraction (mean)	0.98(0.91)	0.96(0.98)	0.73(0.88)	0.414	0.663
Unpredictable toy					
Fear-Trial 1	0.81(0.70)	0.67(0.56)	0.61(0.61)	0.234	0.792
Fear-Trial 2	0.70(0.62)	0.73(0.71)	0.78(0.71)	0.316	0.730
Fear-Trial (mean)	0.83(0.73)	0.73(0.63)	0.69(0.62)	0.029	0.973
Mean Positive-Trial 1	0.86(0.94)	0.99(1.2)	0.96(1.0)	0.036	0.964
Mean Positive-Trial 2	0.77(1.0)	0.90(1.1)	0.83(1.0)	0.101	0.904
Mean Positive12	0.77(0.88)	0.91(1.1)	0.90(0.91)	0.035	0.966
Blocks					
Sustained attention- Trial 1	2.43(0.61)a	2.69(0.35)b	2.74(0.37)b	2,889	0.062
Sustained attention -Trial 2	2.42(0.63)	2.56(0.53)	2.48(0.70)	0.496	0.611
Sustained attention-Trial 3	2.35(0.70)	2.45(0.64)	2.20(0.82)	0.567	0.570
Sustained attention (mean)	2.38(0.57)	2.58(0.38)	2.47(0.50)	1,351	0.266
Effortful control battery					
Snack delay					
Inhibition-Trial 1	7.40(2.7)	7.82(2.4)	6.96(2.7)	0.648	0.526
Inhibition-Trial 2	7.24(2.7)	6.74(3.0)	7.15(2.9)	0.169	0.845
Inhibition-Trial 3	6.45(1.2)	6.29(3.1)	6.19(1.9)	0.164	0.849
Inhibition-Trial 4	7.20(2.6)	6.86(2.8)	7.28(2.1)	0.200	0.819
Inhibition-Trial (mean)	7.12(2.3)	6.96(2.3)	6.86(2.2)	0.040	0.960
Tower					
Inhibition-Trial 1	16.9(2.3)	15.6(3.7)	14.4(4.0)	1,849	0.165
Inhibition-Trial 2	15.6(3.5)	15.9(3.6)	15.0(3.6)	0.286	0.753
Tower inhibition (mean)	16.5(2.4)	15.7(3.7)	14.7(3.5)	1,059	0.352
Wrapped gift					
Peak and turn	1.90(1.29)	1.68(1.03)	1.83(1.15)	1,798	0.184
Touch	3.36(1.14)	3.11(1.58)	3.37(1.03)	0.284	0.753
ECBQ	(<i>n</i> = 21)	(<i>n</i> = 22)	(<i>n</i> = 26)		
Effortful Control	4.78(0.57)	4.75(0.58)	4.63(0.49)	0.878	0.421

(Continued)

TABLE 3 (Continued)

	VPT-control	VPT-music	Full-term		
	mean(SD)	mean(SD)	mean(SD)	<i>F</i>	<i>p</i>
Negative Affectivity	3.56(0.66)	3.31(0.49)	3.28(0.40)	1,070	0.349
Surgency-Extraversion	4.73(0.62)	4.73(0.60)	4.62(0.47)	0.223	0.801

Boldface entries indicate significant difference ($p < 0.05$); a,b,c: different letters significant difference at $p < 0.05$.

significant group effect ($F(2,86) = 3.51$, $p = 0.035$, $\eta^2_p = 0.082$, observed power = 0.64), with higher scores for FT infants ($M = 99.73$, $SD = 5.9$) compared with the VPT-control group ($M = 92.00$, $SD = 8.6$) and the VPT-music group ($M = 93.43$, $SD = 8.2$). There was a significant effect of sex, $F(1,86) = 6.70$, $p = 0.011$, $\eta^2_p = 0.08$, observed power = 0.73, with females obtaining significantly higher scores across all three groups ($M_{\text{females}} = 95.91$, $SD = 9.4$; $M_{\text{males}} = 91.24$, $SD = 6.5$). For Motor score, a similar pattern emerged, with a significant effect of group ($F(2,86) = 7.12$, $p = 0.001$, $\eta^2_p = 0.15$, observed power = 0.92), with higher scores for FT infants ($M = 105.73$, $SD = 9.8$) compared with the VPT-control group ($M = 93.33$, $SD = 10.2$) and the VPT-music group ($M = 93.26$, $SD = 8.8$) and a significant effect of sex ($F(1,86) = 4.197$, $p = 0.044$, $\eta^2_p = 0.05$, observed power = 0.53), with higher scores for females ($M_{\text{females}} = 96.80$, $SD = 10.8$; $M_{\text{males}} = 92.78$, $SD = 9.3$). No significant effect of SES was observed, nor were there any significant interactions.

For the Lab-TAB assessment at 12 months, a significant effect of group emerged in the Unpredictable Toy episode for the variable Fear Trial 2 ($F(2,94) = 10.09$, $p < 0.001$, $\eta^2_p = 0.19$, observed power = 0.98); and significant for Fear Trial Mean ($F(2,100) = 5.162$, $p = 0.007$, $\eta^2_p = 0.099$, observed power = 0.82). A significant effect of group was observed also for the variables: Positive Motor Action for both Trial 1 ($F(2,100) = 0.891$, $p = 0.024$, $\eta^2_p = 0.08$, observed power = 0.69), Trial 2 ($F(2,94) = 3.235$, $p = 0.044$, $\eta^2_p = 0.7$, observed power = 0.60), and for Mean Positive Motor Action ($F(2,100) = 4.311$, $p = 0.016$, $\eta^2_p = 0.084$, observed power = 0.74). Post-hoc analyses revealed that the VPT-music had significantly lower scores for Fear and higher scores for Positive Motor action compared to the VPT-control and full-term groups.

In addition, the Group $\times$ Sex interaction was found to be significant for Fear, Trial 2 ($F(2,86) = 3.846$, $p = 0.025$, $\eta^2 = 0.076$, observed power = 0.69) and Fear Mean ($F(2,86) = 3.846$, $p = 0.025$, $\eta^2_p = 0.076$, observed power = 0.69), as well as for Positive Motor Action, Trial 2 ($F(2,86) = 3.846$, $p = 0.025$, $\eta^2_p = 0.076$, observed power = 0.69) and Positive Motor Action Mean value ($F(2,86) = 3.846$, $p = 0.025$, $\eta^2 = 0.076$, observed power = 0.69). For Fear Mean, the full-term subgroup males showed higher scores than females (the difference was significant at the t-test, $t(27) = 2.15$, $p = 0.018$), while the sex differences were not significant in the VPT-music and VPT-control groups. For Positive Motor Action Mean, the VPT-music subgroup males had higher scores than females (the difference was significant at the t-test, $t(38) = 2.42$, $p = 0.021$). No effect of SES was observed.

Moreover, significant effects of sex across the three groups emerged for Sustained Attention, at Trial 3 ($F(1,97) = 6.455$, $p = 0.013$, $\eta^2_p = 0.066$, observed power = 0.71). Scores were significantly higher for males (Trial 3: $M_{\text{males}} = 2.32$, $SD_{\text{males}} = 0.68$ vs. $M_{\text{females}} = 1.91$, $SD_{\text{females}} = 0.82$; Mean value:

$M_{\text{males}} = 2.41$, $SD_{\text{males}} = 0.53$ vs. $M_{\text{females}} = 2.22$, $SD_{\text{females}} = 0.57$).

Finally, significant effects for Sustained Attention Mean value ($F(1,103) = 4.28$, $p = 0.041$, $\eta^2_p = 0.042$, observed power = 0.82). For the three dimensions of IBQ, no significant effect was observed.

3.2 At 24 months

Table 3 presents the findings from the clinical assessment of preterm-born children at 24 months corrected age.

No significant effect of the music intervention on Bayley-III scales was observed at 24 months. Ancova results revealed a significant effect of sex for Cognitive scores ($F(1,83) = 4.432$, $p = 0.039$, $\eta^2_p = 0.054$, observed power = 0.55), with higher scores for females in all three groups ($M_{\text{females}} = 101.83$, $SD = 10.65$; $M_{\text{males}} = 97.67$, $SD = 10.2$). Additionally, a significant effect of SES was observed ($F(1,83) = 4.166$, $p = 0.045$, $\eta^2_p = 0.051$, observed power = 0.52). For Language score, a similar pattern emerged, with a significant effect of sex ($F(1,83) = 5.511$, $p = 0.021$, $\eta^2_p = 0.07$, observed power = 0.64), again with higher scores for females ($M_{\text{females}} = 93.98$, $SD = 9.30$; $M_{\text{males}} = 89.28$, $SD = 11.28$). Additionally, also a significant effect of SES was observed ($F(1,83) = 5.673$, $p = 0.020$, $\eta^2_p = 0.024$, observed power = 0.21). Correlations indicated that as SES scores decrease, scores on both Bayley scales increase (cognitive: $r = -0.21$, $p = 0.05$; language: $r = -0.23$, $p = 0.03$), suggesting that higher levels of family SES are associated with higher cognitive and language scores. No significant effects were found for the Motor Scores.

At 24 months, for the 4 episodes of the Lab-TAB and the 3 tasks of the Effortful Control Battery, the only significant effect of group emerged for Negative Motor Actions ($F(2,83) = 4.729$, $p = 0.012$, $\eta^2_p = 0.11$, observed power = 0.78) of the Puppet game. Post-hoc analyses showed that VPT-music had significantly lower scores compared to both VPT-control and full-term groups ($p < 0.05$). No other significant effects emerged.

No significant group effect was found for the three dimensions of ECBQ.

4 Discussion

This study examines how early environmental enrichment through music during hospitalization affects infants' temperament - including emotional abilities and attentional capacity, effortful control and neurodevelopmental outcomes in VPT infants at 12 and 24 months corrected age.

Significant effects were observed on few aspects of the infant's emotional abilities at 12 months, with medium-large effects sizes. The

VPT-music had significantly lower scores for Fear and higher scores for Positive Motor action compared to the VPT-control and full-term groups. Note that the coding of the variable Positive Motor action encompassed all movements involving pointing, reaching or grabbing the mechanical toy during the fear test. Infants who were exposed to music attempted to grasp the object, thus performing a proximity action in relation to the task, as opposed to a freezing response, typical of a fear reaction. The observed diminished fear response accompanied by an increased positive motor action to an apparently frightening object in the VPT-music group should be interpreted considering previously reported results in the literature and prior findings related to the brain effects of music listening in the NICU. Langerock et al. (2013) have previously shown that preterm infants present decreased fear levels at 12-months in comparison to full-term newborns when assessed using Lab-TAB battery. This finding at 12 months of age was interpreted as a developmental delay in preterm infants regarding preterm infants' fear response at an early stage. However, decreased fear response to a mechanical toy could also be interpreted as a better emotion regulation. It should be noted that our study shows no significant difference in fear responses assessed by Lab-TAB at 12- and 24-months between VPT- control and full-term infants.

Interestingly, our previous pilot study suggested the potential long-term benefits of early music exposure on preterm infants' temperament at 12 and 24 months of age (Lejeune et al., 2019). Results showed that the scores of VPT were different from those of full-term children for fear reactivity at 12 months and for anger reactivity at 24 months. These significant differences were less important between the VPT group receiving a music intervention and the full-term group than between the VPT group without music intervention and the full-term group. These results, although significant, were obtained with a small sample size.

Of notice, the decreased fear response that we find in the music group at 12 months was no longer significantly different from the other groups at 24 months, which is consistent with previous findings from our pilot study showing no differences between groups regarding fear reactivity by 24 months (Lejeune et al., 2019). Our results suggest thus an effect of the music intervention specifically in early emotional regulation maturation at 12 months, namely in fear responsivity, but no longer evident at 24 months, when also no differences are observed between VPT-control infants and full-term newborns.

Note that no significant differences were found in both IBQ at 12 months and ECBQ at 24 months questionnaires regarding the fear reaction between the three groups.

This response is likely a transient and subtle effect, influenced by other factors such as maternal sensitivity, which we plan to control for in future studies (Gartstein et al., 2018).

Music's impact on emotional regulation has been thoroughly studied in different educational and therapeutic environments. Music has demonstrated significant impacts on mood control, stress alleviation, and emotional communication (Juslin and Västfjäll, 2008). Music has the potential to adjust arousal levels and elicit various emotions, making it an effective therapeutic tool, improving emotional well-being and resilience, among other things (Fancourt et al., 2014).

Neuroimaging studies have shown that children and young adults born preterm frequently show a reduction in the volume of important brain structures, such as the amygdala and hippocampus. In particular, FT infants were shown to present larger amygdala volumes in

comparison to VPT at term-equivalent age (Cismaru et al., 2016; de Almeida et al., 2020). This same early music intervention, delivered during the NICU stay, was shown to significantly increase amygdala volumes in VPT infants exposed to music, compared to those not exposed to music, at term-equivalent age. In fact, amygdala volumes of VPT infants exposed to the music intervention were similar to those of full term newborns (de Almeida et al., 2020). Furthermore, VPT infants exposed to the music intervention also presented an increased maturation of the uncinate fasciculus at term-equivalent age, in comparison to the VPT-control group (de Almeida et al., 2020), as well as a significantly longitudinal increased maturation of the cortical insulo-orbito-temporopolar complex (de Almeida et al., 2023). The uncinate fasciculus is an associative white matter tract connecting parts of the limbic system in the temporal lobe, comprising the hippocampus and amygdala, with frontal regions, such as the orbito-frontal cortex. The orbito-temporopolar cortical complex corresponds to a cortical structural that is connected by the uncinate fasciculus. All these structures are involved in processing of affective stimuli (Kringelbach, 2005), evaluation of emotional association (Wildgruber et al., 2005) and top-down modulation of behavior (Ghashghaei and Barbas, 2002). These regions mentioned are thus essential parts of the fear conditioning circuitry in the brain, with key functions in processing and controlling emotions, especially fear and anxiety. Here we demonstrated that VPT infants exposed to music showed decreased fear behaviors and displayed more positive motor action. Early exposure to music may also enhance the development of adaptive fear responses, reflecting a more advanced emotional regulatory ability. However, further studies correlating the brain structure with clinical behavioral assessments are needed to better understand this relationship.

At 24 months, VPT-music group had lower scores for negative motor actions in the joy task, compared to both VPT-control and FT groups. In this episode, negative motor actions indicate that the child is unwilling to participate in joyful, playful tasks, suggesting a reduced level of engagement in shared playful activities. Children usually show happiness by actively engaging and interacting during these activities. The VPT-music group showed less negative motor behaviors, which can be interpreted as a greater willingness to engage and interact in activities aimed at evoking joy and play, showing less reluctance or refusal behaviors.

Exposure to music at a young age may therefore have a positive impact on a child's inclination to participate in enjoyable and playful activities (Croom, 2015). The results suggest that exposure to music at a young age may improve a child's emotional responsiveness and participation in pleasurable activities.

Lastly, a potentially interesting finding emerged regarding the tendency toward higher scores for sustained attention at Minute 1 at 24 months of age among the VPT group who received a music intervention. The importance of this finding highlights the potential benefits of early music intervention to mitigate attention-related challenges in VPT-born children and adolescents. Extensive research has demonstrated that VPT-born children face a significantly higher risk of attention-deficit disorder compared to their full-term counterparts (Treyvaud et al., 2014). Given the importance of sustained attention in academic, social, and daily functioning, interventions aimed at enhancing attentional abilities hold considerable promise for improving outcomes in this population. The early exposure to music, as observed in our study, appears to play a

role in sustaining attention levels in preterm infants. However, it is crucial to interpret our findings with caution, because although promising, the contrast are not significant, only a tendency toward better scores are highlighted and limited to the first minute of the task.

It is worth to note that at 12 months, no significant differences were found between the two VPT groups in terms of cognitive, language and motor scores as assessed by the Bayley-III scales and at 24 months no significant differences were found between all groups which speaks to our overall well developing preterm groups.

Although early music and vocal interventions have demonstrated beneficial effects in cognitive and affective brain regions right after the interventions (Kostilainen et al., 2021; de Almeida et al., 2020; Lordier et al., 2019; Webb et al., 2015), the persistence of these effects and their influence on infants' neurodevelopment remains a complex issue to evaluate. The present results are in line of most of the studies investigating the long-term impact on infant's cognitive, linguistic and motor development, which found no relevant effect (Kostilainen et al., 2023; Haslbeck et al., 2021; Lejeune et al., 2019). It is also crucial to acknowledge that the Bayley-III has been subjected to criticism (Månsson et al., 2021), particularly for its sensitivity to linguistic and vocal affective nuances. This sensitivity would be enhanced by a careful acoustical and "musical" evaluation, which would enable the disentanglement of the emotional prosody perception and production abilities in the preverbal and early verbal period.

SES was a significant predictor of cognitive and language scores at 24 months, with a more favorable SES correlating with higher Bayley-III scores in these domains. These findings are consistent with previous studies, identifying SES as a significant prognostic factor of premature infants' cognitive outcome during infancy and early childhood (Gui et al., 2019; Linsell et al., 2015; Pittet-Mettrailler et al., 2019). Interestingly, females presented significantly higher cognitive and language Bayley-III scores at 24 months across groups. Similar findings have been reported in literature, showing that male preterm infants are at higher risk of cognitive impairment in comparison to females (Hintz et al., 2006; Skiöld et al., 2014; Wood et al., 2005).

Our study suggests thus that early music listening in the NICU may impact later emotional regulation and responsivity, as well attention capacities in children. Further research with larger sample sizes and extended follow-up periods is warranted to validate and extend our preliminary findings.

5 Limitations

One of the major limitations of the present study is the small sample size, partly due to the halt in recruitment during the COVID-19 pandemic, and partly due to high rate of attrition, with many parents finding it difficult to return for follow-up assessments and to complete questionnaires.

Surprisingly, the socio-economic status (SES) of the parents of the children lost to follow-up at 12 and 24 months was higher than that of the children who took part in the follow-up. This could be attributed to the fact that, in high SES families, both parents often work, which may limit their availability and time to participate in additional studies. In addition, these families often move because of professional obligations, which makes it more difficult to

maintain contact with the clinic and results in a higher drop-out rate.

Another major limitation is that measures of the recruited children's daily musical experience at home were not collected. It is known that practicing a musical experience in a home-based environment can impact on infant's development, with important effects, between others, on language acquisition (Franco et al., 2024). In the present intervention, no sustained musical activities with family members were supported and supplemented by musical activities at home during the infant's first months. In fact, during the music listening experience the babies were laying in their bed. The music was played mostly in a moment when the parents could not be present, with the idea of providing a sensory stimulus to the baby, when no other interaction was being provided. Moreover, we have no information on whether the control group was exposed to music apart from the study, either during their hospital stay or at home. Therefore, we cannot exclude the possibility that the results were influenced by parents' or carers' non-monitored music exposure. This limitation emphasizes the need for future research to pay meticulous attention to the monitoring and regulation of auditory stimulation outside the study design periods.

Another limitation is the lack of highly sensitive tools for behavioral assessment of emotional regulation in early infancy. Future research should focus on these limitations to better understand the long-term effects of a neonatal music intervention. Additionally, the present intervention was based on a recorded stimulus. The administration of a live and directed musical intervention could offer to the preterm newborns an optimal bioecological niche for developing emotional relationship with carers (Browne, 2017).

Moreover, with the present experimental design, we cannot determine if the overmentioned effects were directly related to the music selection offered instead of culturally relevant or family preferred music, as there has been no comparison between familiar and unfamiliar musical pieces. However, based on our previous findings, we can assess that following the continuous exposition to the same musical pieces during the hospital stay, a memory and a degree of familiarity to the musical stimulus is evidenced at a brain level (Loukas et al., 2022).

To conclude, we can hypothesize that during pregnancy a familiarity and a preference for the songs of kin is built (Loewy, 2015), but we can also add that the exposition to new musical pieces impacts on the resting state of preterm infants exposed to music.

Finally, in general, evaluating the long-term clinical effects of early intervention studies using music as an enriching stimulus presents major challenges. These challenges arise for three primary reasons. Firstly, the study population is frequently limited and focused on short-term outcomes, which can hinder a comprehensive understanding of long-term effects. Secondly, the post-hospitalization phase is influenced by numerous variables, particularly those tied to the caregiver-child relationship and the socio-economic environment, which impact the musical environment at home and the ability to pursue subsequent musical experiences.

Moreover, the influence of post-hospitalization factors is crucial for infant's development. We hypothesize that integrating families into music interventions might help to achieving lasting effects beyond the initial neonatal period. Thirdly, a crucial aspect that remains uncertain is how long the structural and functional changes in the infant brain associated with early music intervention, persist.

The dynamic nature of brain development underscores the complexity of this question. While early music and voice interventions have shown promise in inducing positive changes in both cognitive and affective brain areas (de Almeida et al., 2020; Kostilainen et al., 2021; Lordier et al., 2019b; Webb et al., 2015), the stability of these effects remains challenging to ascertain. Continued research and longitudinal studies are essential to unravel the persistence of these positive modifications at a brain level over time.

5.1 Suggestions for future practice and research implications

To summarize, the overmentioned limitations should be addressed in future research and practice. First, unmonitored music exposure at home or in the hospital may affect research results, thus future studies should monitor and regulate auditory stimulation beyond the study times. Sustained musical activities at home, possibly with family members, may enhance linguistic and emotional development in infants.

Future study should use bigger sample numbers to overcome recruitment and attrition, especially during follow-up evaluations, and data on the infant's daily musical experiences at home might help explain how home-based exposure affects development. The lack of sensitive measures to assess emotional regulation in early infancy shows a gap in our knowledge of newborn music therapies' long-term consequences, which should be studied in future investigations. Finally, longitudinal studies are needed to determine how long early music exposure's positive effects on brain development last.

6 Conclusion

The robustness and generalizability of the long-term effects of early music intervention for preterm newborns in the NICU remains challenging. Promising effects on children's emotional development have been highlighted in the present study, but larger sample sized studies are needed to evaluate the clinical impact of a music intervention, that has demonstrated brain changes at term equivalent age (Lordier, 2019; Haslbeck et al., 2020; Kostilainen et al., 2021; de Almeida et al., 2023).

Understanding the long-term impact of early music interventions on preterm infant's clinical outcomes is essential for adapting effective strategies that support positive actions and guide developmental music interventions throughout the child's growth trajectory.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the Research and Ethics Committees of the University Hospital of Geneva. The studies were conducted in accordance with the local legislation and

institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

MF: Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. LL: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing. FL: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. JA: Conceptualization, Investigation, Writing – original draft, Writing – review & editing. PH: Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing. FB-M: Investigation, Writing – original draft, Writing – review & editing. MM: Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. CB-T: Conceptualization, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Euterpe music therapy methodology and procedure algorithms

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Introduction: As highlighted by the scientific literature, music therapy (MT) represents a significant non-pharmacological intervention within neurorehabilitation programs. MT offers benefits in the recovery process and enhances the quality of life for patients with neurodevelopmental disorders. A review of the literature reveals a lack of MT models focusing on real-time personalized composition using electronic music techniques. Furthermore, studies on MT conducted within a multisensory therapeutic context are limited. Recent literature reviews on MT in telerehabilitation have highlighted that the application of the Euterpe Method (EM) is complex due to limited technical information available and the combined background required for music therapists to replicate the EM protocol.

Methods: This paper presents a manual which specifies the procedures and algorithms of the EM, developed during a research program conducted in a pediatric hospital in Italy. The prerogative of the EM is the use of procedures aimed at creating personalized therapeutic compositions within a multisensory environment.

Discussion: The efficacy and resilience of the EM have been demonstrated in two experimental studies. The first focused on the use of telerehabilitation in children with developmental disorders, while the second involved hospitalized children with cerebral palsy.

Conclusion: This study integrates medicine, neuroscience, and MT to develop personalized interventions in pediatrics, fostering collaboration among specialists and families, enhancing patient well-being, and opening new therapeutic perspectives, while ensuring the replicability of the EM approach.

KEYWORDS

music therapy, Euterpe method, rehabilitation, children, sleep quality, parental distress, quality of life, cerebral palsy

1 Introduction

The use of music as therapy has ancient origins, initially intertwined with myths, cosmologies, and theories of the ancient world. In many myths and popular narratives, sound is often conceived as the primordial substance from which the universe originates. Early historical references include Egyptian medical papyri dating back to before 1,500 BCE, Book III of Plato's Republic, and the Arab-Jewish medical tradition (1–8). Over time, musical therapies evolved from shamanic practices to tribal medicine and tarantism (9).

The development and formalization of music therapy (MT) began with the establishment of the first academic program at Michigan State University in 1944, followed by the creation of the National Association for Music Therapy in 1950 (10). This professionalization continued with the founding of the British Society for Music Therapy by Juliette Alvin in 1958, expanding the reach of MT in Europe. In 1985, in response to the increase in experiences and the growing proliferation of MT associations, the World Federation of Music Therapy (WFMT) was established. This organization has played a pivotal role in formalizing the discipline by defining ethical, deontological, and professional standards, as well as promoting a shared definition of MT at the international level (11). To support this process of disciplinary structuring, during the 9th World Congress of Music Therapy in 1999, five main models of MT practice were formally recognized, developed by authoritative figures in the scientific community such as Bonny (12), Priestley (13), Nordoff and Robbins (14), Benenzon (15), and Madsen (16).

With the evolution of MT methodologies, techniques have been further refined through the integration of neuroscientific knowledge and the use of new musical technological instruments. In this context, scientific reviews have highlighted that musical improvisation is a prevalent strategy in numerous MT methodologies, as it facilitates emotional expression and increases therapeutic effectiveness (17–19).

These characteristics are identifiable in the approaches of Priestley and Nordoff-Robbins, whose therapeutic models closely align with our clinical practice, being based on musical improvisation and the creation of compositions specifically tailored to the patient's needs (20). In parallel, the work of Anne Riordan and Kenneth E. Bruscia has introduced dance as a complementary therapeutic element in musical improvisation, demonstrating how the integration of this dimension promotes improvements not only in emotional and social skills but also in the patient's cognitive and motor abilities (21).

Although the use of musical improvisation promotes creative expression, it introduces a degree of unpredictability that may not be suitable for all patients. Indeed, the absence of a predictable structure can make it challenging to maintain a clear therapeutic focus, potentially compromising the effectiveness of the intervention.

Bruscia has also highlighted, from an applied perspective, a range of risks and limitations associated with the patient. These include the need for adequate cognitive and sensorimotor skills to engage in musical improvisation. There is also the risk of adverse psychological reactions to music, such as hallucinations, difficulties in auditory processing, and undesirable physical responses. Other side effects include withdrawal, obsessions, compulsions, and sensory overload. Lastly, the author advises paying attention to interpersonal dynamics that may be threatening to the patient (22).

To prevent the risks associated with improvisation in MT, it is essential to tailor sessions according to the patient's psychophysical

condition, ensuring safe participation and preventing frustration. It is equally important to carefully monitor adverse psychological reactions and side effects, selecting musical materials with precision, and adjusting the intensity of the treatment. The therapist must meticulously consider the patient's sociocultural context, respecting musical traditions to prevent cultural dissonance that could undermine the effectiveness of the therapeutic intervention. Contextually, the integration of innovative musical technologies can significantly enhance the patient's auditory processing and mitigate the impact of potentially disruptive sound stimuli.

Scientific reviews highlight how such technologies can significantly enhance the therapeutic potential of MT. Consequently, these technologies applied to electronic composition can be tailored to meet the specific needs of patients (23–27). Supporting this, Farnan defines composition as “custom designed” music (25). Jones supports the value of composition, emphasizing the need for further research on best-practice models for clinical objectives (26). Barta et al. demonstrate the value of real-time music composition in the rehabilitation of patients with Parkinson's disease (27). These findings are supported by the review conducted by Vinciguerra et al., which demonstrates that MT improves motor function and cognitive abilities in patients diagnosed with Parkinson's and Alzheimer's diseases, as well as stroke. This result emphasizes the significance of musical temporal structures in enhancing motor coordination and memory. In addition to its applications in neurodevelopmental disorders, MT has also demonstrated significant non-pharmacological benefits in managing chronic neurological diseases such as multiple sclerosis. The authors highlighted the role of MT in enhancing emotional well-being and cognitive functions in multiple sclerosis patients, demonstrating its broad therapeutic potential in neurorehabilitation (28).

Another aspect considered in our study is the limited number of research studies on MT in a multisensory context. Although some reviewed studies report sound or compositional interactions in relation to the environment, there are no specific references concerning the interactions between the environment, musical activities, and intervention methodologies (29–34). Marti et al. evaluated the effectiveness of MT therapeutic protocols in a multisensory environment for the treatment of dementia (29). Maseda et al. and Latham et al. further explored the effectiveness of non-pharmacological interventions in multisensory environments on patients with dementia, using different therapeutic approaches. Maseda et al. explored the use of unstructured stimuli autonomously chosen by patients, while Latham et al. evaluated Simard's Namaste Care program, which combines scents, lighting, sensory objects, and music to create a relaxing atmosphere, employing personalized playlists only when necessary (30, 31). However, the studies present methodological limitations, particularly regarding the interaction between multisensory stimulation and the musical component. Lee and Li reported a school study focused on the impact of therapeutic musical activities in a multisensory environment for children with multiple disabilities, aimed at promoting positive emotional development (32). Cappelen and Andersson introduced an interactive multisensory environment that integrates music composition, design with the therapeutic principles of music, MT, and sensory integration to promote health through technology (33). Challis et al. presented two case studies that question current trends in the design and allocation of resources for multisensory environments, emphasizing

the creation of functional spaces rather than simple technology aggregates (34).

The literature review has identified significant biases in the field of MT, including the limited application of real-time personalized electronic composition techniques.

Moreover, most existing approaches focus on environmental setup and the use of musical instruments, without fully considering the role of the environment as a sensory amplifier (2, 12, 15, 22). When used correctly, the environment could function as a sensory “mixer,” modulating and enhancing the effectiveness of the intervention.

Finally, although the Euterpe Method (EM) has demonstrated its efficacy in the context of both neurorehabilitation and telerehabilitation (35, 36), subsequent reviews have raised both growing interest and significant criticisms (37–48). Specifically, Paterson et al. have emphasized the importance of implementing telerehabilitation interventions based on MT to address new challenges in modern medicine (39). Concurrently, Le Vu et al. have highlighted the complexity of implementing EM, as it requires interdisciplinary training for music therapists, an aspect that currently limits the method’s replicability and widespread adoption (41).

To address the identified biases, this article proposes targeted interventions aimed at enhancing replicability and interdisciplinary training for music therapists through the use of original EM algorithms and procedures. These algorithms include EM Hospital-based (providing specific clinical goals for each patient), EM Active (live music, real-time compositions, improvisation, interactive workshops), EM Receptive (listening to personalized compositions and electronic music), and EM Telerehabilitation (remote delivery of MT). Furthermore, integrating a multisensory space with compositional activities represents an innovative strategy to amplify MT’s effectiveness, improving the interaction between the environment and therapeutic intervention.

The integration of neuroscience, music, and technology not only opens new perspectives for personalized and clinically optimized therapeutic interventions, but also lays the groundwork for structured innovation in pediatric rehabilitation.

1.1 The Euterpe method

The methodology referred to as Euterpe has a dual foundation. Culturally, Euterpe is one of the nine Muses of Greek mythology, the daughter of Zeus and Mnemosyne, and the protector of music. The name, derived from the Greek words *εὖ* (good) and *τέρπειω* (pleasure), means “she who gives joy.” Pragmatically, it reflects the intent to develop a methodological approach tailored to the individual needs of patients and therapeutic goals, in close collaboration with the music therapist and the medical team.

EM is designed for children with neurodevelopmental disorders, actively involving parents, typically the mother, during therapy sessions.

EM uses original, customized *Compositional Sound Interventions* (CSI) and structured therapeutic activities based on specific algorithms. Music and CSI form the foundation for creating *Personalized Therapeutic Compositions* (PTCs), which constitute the core of EM therapy.

Therefore, PTCs can be defined as a series of articulated processes of specific sound stimuli, technically processed and adapted to the

patient’s individual needs during therapy. These sound processes are simultaneously associated with multisensory stimulation within an enriched environment.

In order to delve deeper into the process of PTC realization and implementation, we feel it is essential to present a brief excursus.

As widely acknowledged, music has a significant impact on mood and emotions. This effect occurs because sound stimuli exert a sensory and psychological response in each individual, inducing a corresponding emotional reaction (49–51).

In support of the above, anthropologist Alan Parkhurst Merriam identifies 10 functions for music, representing opportunities to express emotions, thoughts and ideas (5).

Numerous musicological studies affirm that a musical work is structured as a series of more or less lengthy musical segments, arranged in a functional “hierarchy” that determines their role and importance (52, 53).

These studies suggest an affinity between personalized musical composition and the creation of a therapeutic context that resonates with the patient’s experiences, needs, and aspirations.

In the creation of PTCs, the compositional sound material derived from the patient’s “positive” reactions assumes a “*hierarchical perceptual function*.” This function reflects the patient’s ability to interpret and respond to musical stimuli according to their subjective perceptions, which are intimately tied to their somatosensory condition and psychophysiological state.

The implementation of the PTC develops through an articulated temporal flow, composed of “sound cells,” compositional structures, and specific timbres. These components impart a dialogic quality to the PTC, in which sound sequences alternate in a rhythm of “coming and going,” presenting the composition as a sound dialog of questions and answers, clearly distinguishing a “before” and “after.” This compositional development does not conform to predetermined musical forms, as it is solely guided by the therapeutic question: “*Does this intervention improve the patient’s quality of life?*” However, it is noteworthy, upon subsequent musicological analysis, that PTCs reveal similarities with pre-existing musical forms and musicological philosophies. This highlights how musical perception is an acquired anthropological construct, reflected in specific compositional processes. Below are examples that overlap with the compositional techniques of PTCs.

During EM therapy, a relevant example is guiding the patient to listen to silence and the sounds produced by the environment. This approach aligns with John Cage’s philosophical idea of 4’33”, a composition consisting entirely of silence, where the listener is confronted only with environmental sounds, the only tangible source of “music.” The absence of sound in favor of casual and incidental sounds (such as the audience’s breathing or noises inside and outside the auditorium) becomes the new sound material (54). Even more significant is Cage’s composition *Imaginary Landscape No. 4*, performed with 12 radios and 24 performers, where the listening result is always unique and unrepeatable due to the simultaneous overlap of sounds, words, and random noises from radio stations. This concept is similar to that of PTCs, with the distinction that every sound variation produced by the patient in the multisensory environment in which therapy takes place is recorded and played back as a new compositional incipit.

A similarity between the compositional structure of PTCs and Lerdahl and Jackendoff’s *Generative Theory of Tonal Music* lies in the

use of generative principles to organize and interpret music. This theory, based on the hierarchy of tensions and relaxations, as well as processes of continuity and discontinuity, finds a parallel in PTCs, where sound events like the mother's prosodic voice and the patient's reactions alternate in a rhythmic loop, creating dynamic contrasts between tension and relaxation (55–57).

Additionally, minimalist styles from composers such as Terry Riley, Steve Reich, Philip Glass, and John Adams can be identified, as they conceptualize a “gradual musical process” based on repetition, variation, and structural prolongation of rhythmic and melodic segments (58).

Similarly, the cluster technique employed by György Ligeti (59) can be recognized. This approach consists of modifying through “addition” or “subtraction” complexes of chromatic and diatonic sounds, as nuances of a sound spectrum, creating micro-polyphonies that alternate in a compositional continuum.

Finally, the choice and use of electronic music for PTCs in EM therapy. It is important to note that electronic music originates from recording, listening, and developing electroacoustic instruments.

In fact, electronic composition is directly related to the sound material, unlike traditional composition, which uses symbolic writing (notation) to represent the gestures to be performed on a musical instrument to play a song.

The evolution of electronic composition has traversed research sector, progressing through stages such as phonography (a means of capturing and reproducing sounds while keeping them identical), radiophony (enabling real-time live transmissions over long distances), and electric and electronic lutherie (offering innovative musical instruments). The evolution of computers has made it possible to combine the characteristics of phonography, radiophony, and electronic lutherie into electronic composition. Finally, ongoing developments in computer technology, research, and new tools have consistently advanced the sector of electronic music, drawing attention and encouraging scientific studies across a wide range of disciplines, including MT.

Electronic music was born in Cologne in 1950 by Herbert Eimert. The growing interest in this domain among scholars led to the establishment of significant research centers, notably: the Studio di Fonologia Musicale, founded by Bruno Maderna and Luciano Berio in Milan in 1955 (60); the Équipe de mathématique et d'automatique musicales (EMAMu), founded by Xenakis in 1966 (61); and the Institut de coordination acoustique/musique (IRCAM), established by Boulez in Paris in 1975 (62).

Key advantages of using electronic music in MT include the creation of therapeutic orchestral scores with virtual instruments and real-time interaction with the patient. Additionally, electronic music enables customization of sounds and synthesis effects tailored to the patient's psychophysiological conditions and clinical objectives.

Examining the context of the previous discussion regarding the scientific-musical excursus that encompasses the emerging forms derived from PTC and the importance of electronic composition, a reflection arises on the context in which MT interventions take place.

The spaces dedicated to musical listening in various contexts are continuously evolving, influenced by research on acoustic techniques. It is essential to deepen the understanding of the environments in which MT activities occur, as these contexts can significantly impact the effectiveness of the MT sessions.

According to Altenmüller and Schlaug, music is not merely an auditory input but represents one of the most enriched experiences in

terms of emotional, sensory, and cognitive dimensions, influencing and modulating the activity of brain regions involved in multisensory and motor integration, including frontal, parietal, and temporo-occipital regions (63). This multisensory brain activation is closely associated with the phenomenon of neuroplasticity. Neuroplasticity, or cortical remapping, involves reconnecting previously disconnected brain areas through new neural connections or strengthening existing ones. This process occurs in response to learning new skills, memory formation, recovery from injuries, and experiences of sensory deprivation or environmental enrichment (64).

Based on these studies (63, 64), the environment is configured as a determining factor that influences and contributes osmotically to the effectiveness of therapeutic sessions, facilitating the interaction between external stimuli and the patient's psychophysiological processes.

There is limited research investigating the correlation between sound and environment in MT practice. However, examined studies have shown that the acoustic environment can modulate individuals' emotional and behavioral responses, thus impacting MT effectiveness (65, 66).

Our research aims to implement sound activities into MT, recognizing that these activities extend beyond mere sound production, engaging all the senses. According to a study by Lee and Li (32), multisensory musical experiences can promote greater participation and emotional engagement, thereby enhancing the therapeutic effects of music.

Furthermore, it is important to consider the role of physical and social environments in facilitating or hindering the therapeutic process. Research by Wigram, Pedersen, and Bonde has demonstrated that the design of spaces dedicated to MT can affect group dynamics and perceptions of social support, thereby improving the overall efficacy of the sessions (67).

Based on the above considerations, EM sessions are conducted in a specially designed environment known as the “Synesthesia Room” (SR), equipped with specific materials and instruments aimed at providing complex and appropriate sensory stimulation. The therapeutic activity, referred to as “Sound in Multisensory Stimulation,” integrates the environment through the control and customization of sound stimuli, facilitating the simultaneous overlay of multiple sensory stimuli. The goals of the therapy are to improve, motivate, create, implement, and learn behaviors in the socio-communicative, affective-relational, psychomotor, cognitive, and neuropsychological domains (68).

Currently, the EM is employed in various clinical settings, including neurorehabilitation units, oncology departments in the Middle East and Europe, and MT associations.

1.2 The Euterpe method and the environment

The SR is an environment specifically designed and structured for EM therapy, which employs multisensory integration simultaneously with MT activities, considering it an integral part of the therapy.

The environment and sensory have been the subject of study and research since the 19th century; however, it was in the 1970s that the first rooms equipped for sensory stimulation through visual, auditory, tactile, and olfactory modalities (e.g., the Snoezelen room) were designed and tested (69).

Recent studies have shown that sensory integration engages multiple brain regions, such as the neocortex, basal ganglia, thalamus, and cerebellum. Within this framework, the cerebellum plays a central role in sensory processing, while the anterior motor cortex orchestrates motor programming. Disruptions—whether structural, metabolic, or functional—within these regions, or along their neural pathways, can profoundly compromise sensory processing, contributing to a spectrum of neurosensory dysfunctions (70, 71).

To date, clinical trials have focused on patients with intellectual and developmental disabilities or cognitive disorders such as dementia (70–74). As highlighted by Breslin et al., the therapeutic use of multisensory environments also aims at relaxation, pain management, improved attention, and the reduction of maladaptive behaviors (73).

Furthermore, from a musical perspective, the interaction between sound, environment, and tools has been a subject of scientific interest. Two prominent figures in this field are R. Murray Schafer and Aleksandr Skrjabin. Schafer is known for his studies on the “soundscape,” focusing on the relationship between sound and the natural and urban environment (75). Skrjabin, on the other hand, developed synesthetic theories linking music to colors and tactile sensations, opening new perspectives on the multisensory interaction of music (76). Both authors provide strong theoretical foundations for understanding how sound can be meaningfully integrated into the therapeutic environment and the patient’s experience.

Based on this research, EM therapy has developed therapeutic sound and compositional activities aimed at interacting synergistically with the SR environment. The environment itself is characterized by structural and sensory flexibility, allowing rapid adaptability to the specific needs of the patient.

A distinctive feature of the EM space is its adaptability and ease of configuration, making it suitable for various environments, including the patients’ home settings. The concept of “Mobile Architecture,” applied to the method, allows for the dynamic customization of the therapeutic environment. This flexibility not only optimizes the use of available space but also ensures that EM sessions can be seamlessly integrated into different therapeutic contexts, enhancing both the efficiency and quality of therapy.

This concept of “environmental resilience” has been discussed by Kaplan and Kaplan, who emphasized the importance of a therapeutic setting that can dynamically adapt to the individual needs and preferences of the patient (77).

Therapeutic interventions are designed in unimodal, multisensory, and cross-modal manners to maximize therapeutic efficacy. A unimodal approach may involve the use of a single sensory modality, such as vision or hearing, while a multisensory approach involves the simultaneous activation of multiple senses. Cross-modal stimulation, which engages the interaction between multiple senses, has been associated with enhanced brain plasticity and learning (78).

The therapeutic space of the SR is configured and personalized with specific materials and software to meet the individual needs of each patient, considering factors such as age, pathology, clinical condition, and specific therapeutic requirements (Supplementary 1). This personalization allows the patient to decontextualize the hospital environment, enabling the child to feel like the protagonist within the therapeutic setting. The design of the SR, grounded in robust scientific research, demonstrates that MT interventions in multisensory environments enhance the cognitive, emotional, social, and affective well-being of patients.

2 Materials and equipment

To ensure the proper conduction of EM MT sessions, the music therapist manages a range of devices and technological tools aimed at regulating sensory stimuli. It is important to note that the software specified is provided for informational purposes, and therefore, other programs may be used depending on expertise and specific usage needs. These tools include:

- **Audio Management:** A computer, using a Digital Audio Workstation, handles audio editing software such as Adobe Audition, Pro Tools, FMOD Studio, MPC Beats, Ableton Live, or similar programs. Audio playback is achieved through two active 2.1 systems, each composed of two tops with four speakers in a vertical array configuration and a subwoofer, totaling 1,200 W of maximum power. The setup is complemented by a 12-channel mixer, a 4 In/4 Out audio interface, dynamic and condenser microphones, as well as a sound pressure level meter (cf. Supplementary 2.1, 2.2).
- **Video Management and Projection:** Session recording and study are conducted using fixed and mobile cameras. Fixed cameras record in 4K with HDR technology and a fixed 120° XY stereo microphone, while mobile cameras also allow 4K recordings and are equipped with a mid-side stereo microphone. Projection equipment includes Full HD LED projectors and WVGA LED mini-projectors (cf. Supplementary 2.3).
- **Lighting Management:** Equipment comprises a lighting management station with DMX interface and RGBWA LED moving heads. Light management is carried out through a computer with ADJ MyDMX3 software to control color tones and light intensity (cf. Supplementary 2.4).
- **Musical Instruments and Equipment:** Various types of musical instruments are available for therapists and patients (cf. Supplementary 2.5), while olfactory stimulation is managed through essential oils and essence vaporizers. Additionally, a hammock is permanently installed to promote muscle relaxation and strengthen the patient-parent bond.

3 Methods

This study adopts a hermeneutic approach to deeply analyze the methodologies and procedural algorithms of the EM, integrating original research with a well-established scientific and historical context (79, 80). A rigorous qualitative review of the existing literature on MT practices was conducted, selecting sources of proven relevance and methodological robustness (81). The analysis incorporated data extracted from our previous studies and research as well as clinical reports (35, 36).

To contextualize the results, the historical development of MT was traced, positioning the EM within this broader framework. Key historical references have provided a solid theoretical basis for understanding the evolution and adaptation of therapeutic practices over time (82, 83). The investigation revealed that the EM fits into a historical tradition of therapeutic music use, with ancient roots spread across various cultures (84, 85).

The hermeneutic approach enabled a deep understanding of the experiences of patients and therapists with the EM through

the interpretation of qualitative data (80). To ensure an inclusive and participatory method, the principles of Mertens' transformative approach were integrated (86), actively involving patients, parents, and therapists in the research process. This approach fostered the empowerment of participants and promoted continuous dialog between researchers and the involved subjects, ensuring that their experiences and perspectives were fully integrated into the analysis.

The integration of historical elements and the triangulation of data sources ensured methodological rigor and high validity (87, 88). This combined approach not only facilitated a deeper understanding of the role of the EM in contemporary MT but also highlighted its potential to significantly improve patient well-being and promote the future development of the discipline.

3.1 Study design

This section analyzes the data from two previously published studies, aiming to provide a more detailed and comparative view of the effectiveness of EM in the context of intensive pediatric rehabilitation.

The first study, conducted by Bompard et al., was a prospective single-center study designed to evaluate the feasibility of EM-based telerehabilitation during the SARS-CoV-2 pandemic.

The inclusion criteria consisted of children with developmental delays under the age of 12 who had previously undergone personalized MT sessions prior to the pandemic. Exclusion criteria included the absence of participation in the EM MT pathway during the previous hospitalization.

Participants, regularly enrolled in intensive rehabilitation programs, were assessed using the Gross Motor Function Classification System (GMFCS) to determine their functional status (89). Evaluations were conducted remotely by the pediatric neurologist in collaboration with the parents, both before the start of the program and upon its conclusion. Informed consent was obtained from the parents for data collection and analysis (35). The second study, conducted by Liuzzi et al., was a prospective single-center experimental investigation aimed at evaluating the effects of the intervention on key aspects of the children's and their parents' lives.

Inclusion criteria comprised children aged 0 to 10 years with cerebral palsy (90), hospitalized for 3 to 4 weeks for intensive rehabilitation. Children with severe hearing impairments or deafness were excluded. Participants were randomly assigned to an experimental group, which received MT based on the EM, and a control group, which followed the rehabilitation program without MT. Motor functionality was assessed using the GMFCS (89), and outcomes were measured through the administration of parent-report questionnaires at T0 (study initiation) and T1 (after 3 weeks). Informed consent was obtained from the parents, and an independent evaluator, blinded to the randomization, examined the results (36).

3.2 Euterpe method procedures

EM's distinctive prerogative lies in the use of four original algorithms, each designed to address specific therapeutic aspects with scientific precision.

EM Hospital-based guides the process from patient selection to the definition of target objectives by the hospital team (Supplementary Figure 34; Figure 1).

EM Active constitutes the core procedure of the EM, precisely delineating the *modus operandi* of MT activities (Figure 2).

EM Receptive specifies the protocol for implementing rehabilitative activities on days when active MT sessions are not conducted in the hospital (Figure 3).

EM Telerehabilitation provides therapeutic continuity of MT directly in the patient's home environment, offering the possibility of treatment delivery even in remote or difficult-to-access geographic settings. It can be prescribed by the hospital team or requested by parents, offering a structured pathway for remote therapy (Figure 4).

3.3 EM Hospital-based procedure

The **EM Hospital-based** protocol (see Figure 1) represents a rigorously defined methodological approach aimed at formulating specific clinical objectives for each patient. This protocol is designed to enable its application in various clinical contexts while ensuring interconnection with subsequent algorithms.

The selection of patients for the EM therapy program is carried out by a multidisciplinary team, including physicians, psychologists, head nurses, nurses, and certified music therapists, ensuring an integrated therapeutic approach. The prescription of the EM program is based on inclusion criteria, considering variables such as age, pathology, severity of the condition, and the optimal number of necessary sessions, allowing for precise treatment personalization.

After the patient selection process and before the start of the EM program, parents provide privacy consent for the inclusion of their children in the scientific studies and for video recording of the sessions. Furthermore, questionnaires are provided to the parents, who complete them independently. This allows for a preliminary assessment of both the patient and the parent (T0).

The entire sample is divided into two groups, experimental and control, through blind randomization. Subsequently, the physician and music therapist work closely to review the clinical history of the patients assigned to the experimental group to precisely define the therapeutic goals of the EM MT program. At the same time, the control group follows an intensive neurorehabilitation program without the EM MT intervention. Upon completion of the therapeutic path, which includes both intensive rehabilitation and MT sessions, T1 assessments are conducted for both groups to evaluate the effectiveness of the interventions and compare outcomes between the two groups.

Before discharge, if deemed necessary, the hospital team proposes that families from the experimental group continue the EM at home through the telerehabilitation program.

3.4 EM active procedure

The EM Active constitutes the detailed protocol for practical MT activities, designed according to the specific clinical needs and individualized treatment goals of each patient (Figure 2).

This process is carried out within the SR by a certified music therapist and a certified co-therapist. Activities may include learning exercises with musical instruments, improvisations,

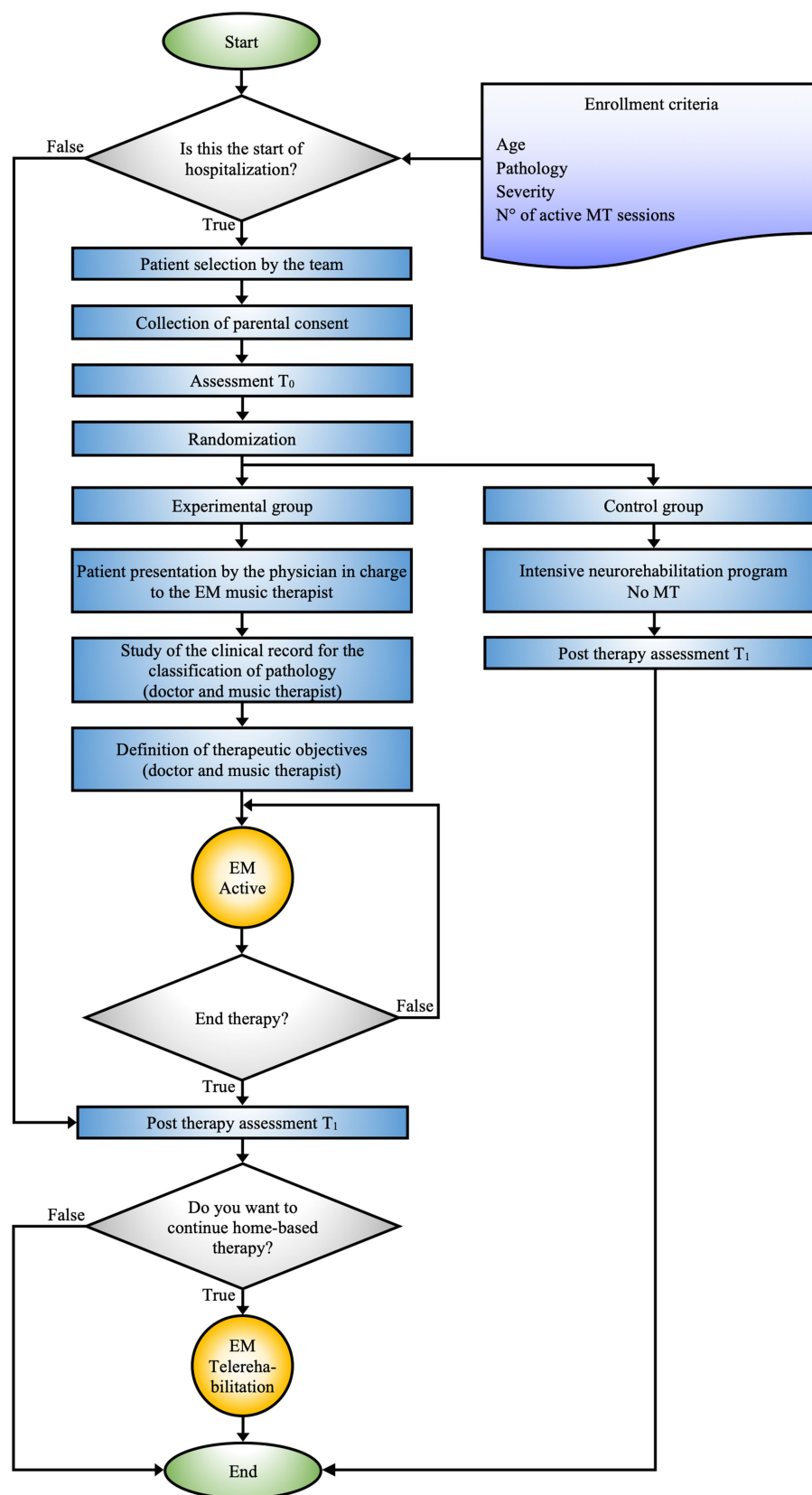


FIGURE 1

EM hospital-based schematic representation of the decision-making and therapeutic process adopted for patient management during hospitalization. The figure shows the integration between personalized MT and intensive rehabilitation programs, with a focus on tailoring the treatment to the specific clinical needs of the patients.

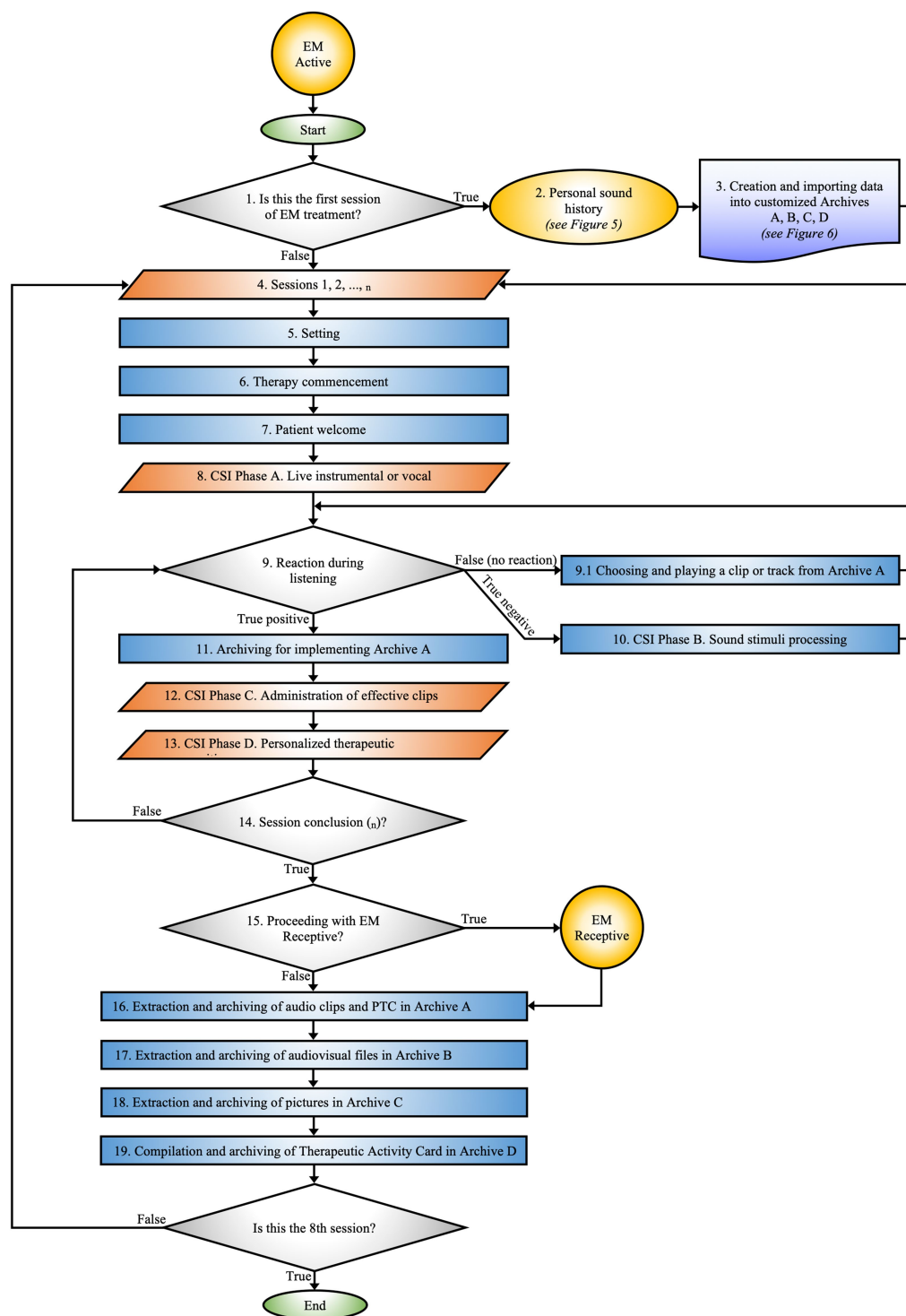


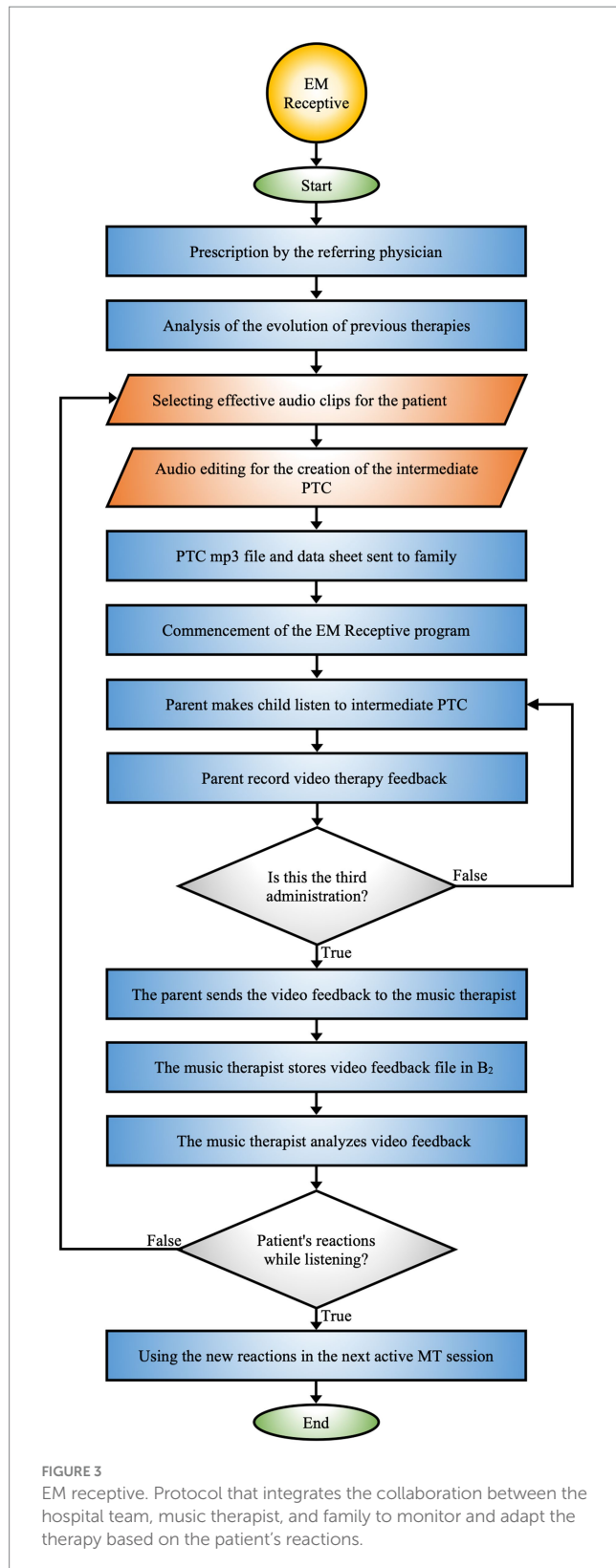
FIGURE 2

EM active. Maps the phases of the therapeutic process from the initial session to data archiving. The flow is guided by the patient's responses to auditory stimuli.

explorations of EmoTonePhonoSymbolisms (91), and sound elaborations, adapted to the patient's needs and therapeutic progress. EM approach involves the administration of sensory stimuli using unimodal, multisensory, and cross-modal techniques, aimed at creating PTC.

3.4.1 Is this the first EM session?

During the initial session, the music therapist informs the parent about the EM therapeutic path and outlines the objectives to be achieved during the rehabilitation intervention. The session comprises an observational assessment of the mother's



psychological state to encourage her active involvement in the therapeutic process and facilitate collaboration for subsequent stages.

3.4.2 Personal sound history

After reviewing the patient's clinical history, the music therapist collects the "Personal Sound History" through the following procedure:

- 1 **Questionnaire:** A structured interview is employed to gather data on the patient's sensory sensitivities, focusing on areas of vulnerability such as photosensitivity, auditory hyperreactivity, olfactory intolerances, tactile difficulties, and feeding issues. This information is essential for constructing a comprehensive sensory profile, which is indispensable for tailoring the therapeutic intervention (Figure 5).
- 2 **Mother's voice recording:** The therapist records various linguistic elements of the mother, such as the prosody of the child's name, baby talk, tenderness, positive reinforcement, and lullabies. The recording is done in a supportive environment to ensure that the mother feels comfortable and motivated.

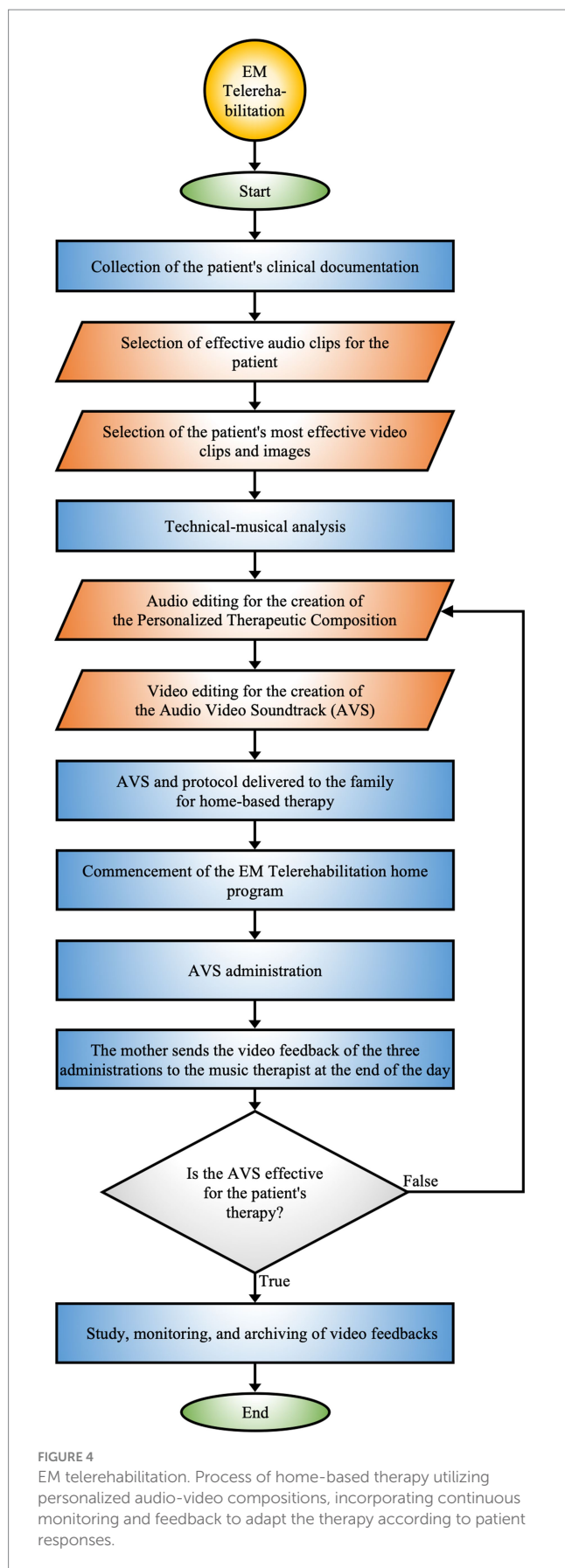
3.4.3 Creation and importing data into customized archives A, B, C, D

The music therapist analyzes the raw recording previously made with the patient's mother, removing background noise and segmenting the audio files, which are then named according to their content. The selected files are used as auditory stimuli for therapy and as a notation of the compositional structure. The database, named after the patient, includes preferences derived from the questionnaire and is structured into four distinct archives (Figure 6; Supplementary 3.1):

- 1 Sound Archive A
 - A₀ Therapist's Sound/Music
 - A₁ Family Sound
 - A₂ Music Known by the Patient
 - A₃ Discomfort Sound
 - A₄ Amniotic Sound
 - A₅ Sound Design
 - A₆ Electronic Noise
 - A₇ Body Sound
 - A₈ Live Music and Instruments Sound
 - A₉ Patient Reaction
- 2 Video Archive B
 - B₀ Video Archive per Session
 - B₁ Effective Video-Reactions
 - B₂ Receptive Procedure Video-Reactions
- 3 Pictures Archive C
 - C₀ Pictures Archive per Session
 - C₁ Effective Pictures
- 4 Therapeutic Activities Archive D
 - Tables detailing the activities performed in each session (Supplementary Figure 14).

3.4.4 Sessions 1, 2,..., n

All sessions are video recorded, an essential step to ensure an accurate evaluation of the patient's responses and provide an in-depth



retrospective analysis of the therapeutic process. This practice also facilitates rigorous documentation and optimizes the design of personalized musical compositions.

The program involves a minimum of eight sessions, conducted three times per week during the patient's hospital stay. The duration of each session, typically ranging from 30 to 40 min, is adjusted based on the patient's age and specific needs. Each session follows a therapeutic structure composed of sequential phases and steps, specifically tailored for each encounter.

3.4.5 Setting

The sessions take place within the SR, a space designed to provide a highly flexible and resilient environment, capable of adapting to various age groups and specific psychophysiological conditions of the patients. This adaptability ensures maximum safety for both the patient and the parent during the therapeutic sessions.

The MT team is responsible for preparing the SR through a series of interventions:

- Cleaning and sanitizing of the surroundings, materials, and musical instruments
- Setting up the workstation
- Organizing sound material for playback, and balancing output signals from software and mixer
- Placement of aids for video recording, control of gain levels, and framing
- Connection and checking of LED lights and mobile LED heads, wired to the DMX interface
- Preparation of software for the touchscreen monitor (digital flipchart)
- Preparation of the projector for augmented reality
- Changing of hammock sheets
- Thorough handwashing and donning of brightly colored clothing by the therapist and co-therapist.

3.4.6 Therapy commencement

During this phase, the music therapist and co-therapist define and coordinate their roles and responsibilities with respect to the patient and the therapy within the therapeutic environment.

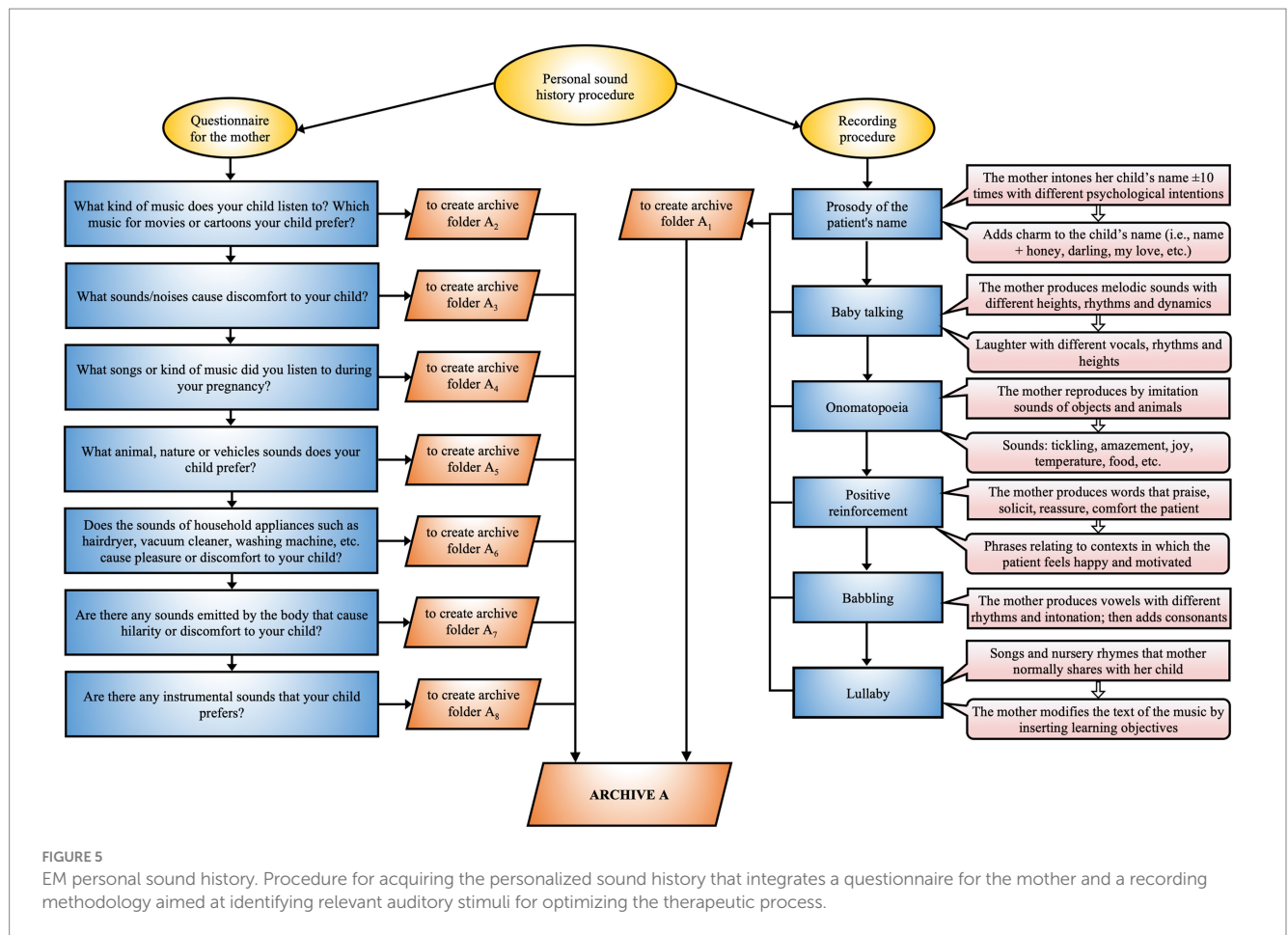
3.4.7 Patient welcome

3.4.7.1 Step 1. Patient observation and feedback with the parent

The therapist assesses the psychophysiological condition of the patient and the parent before starting the therapy, using professional behaviors.

3.4.7.2 Step 2. Patient introduction to the multisensory space

The therapist welcomes the patient and the parent, guiding them through the multisensory environment (SR), which is rich in colors, scents, sounds, and images, and encourages them to explore the space. Constant monitoring and guidance by the therapist are essential to ensure the child's safety and facilitate a smooth transition into the environment.



3.4.7.3 Step 3. Review of the previous session

Before beginning the MT session, the therapist reviews the activities of the previous session with the parent, checking for any changes in the child's behavior and monitoring therapeutic progress. This feedback process ensures that the therapeutic plan remains appropriate to the patient's psychophysiological needs and promotes parental involvement in achieving clinical objectives.

3.4.8 Compositional sound interventions—phase A. Live instrumental or vocal

CSI are structured therapeutic approaches that employ personalized musical and auditory techniques to achieve specific clinical objectives. The CSI process is divided into four phases:

- A Live Instrumental or Vocal
- B Sound Stimuli Processing
- C Administration of Effective Clips
- D Personalized Therapeutic Composition (PTC).

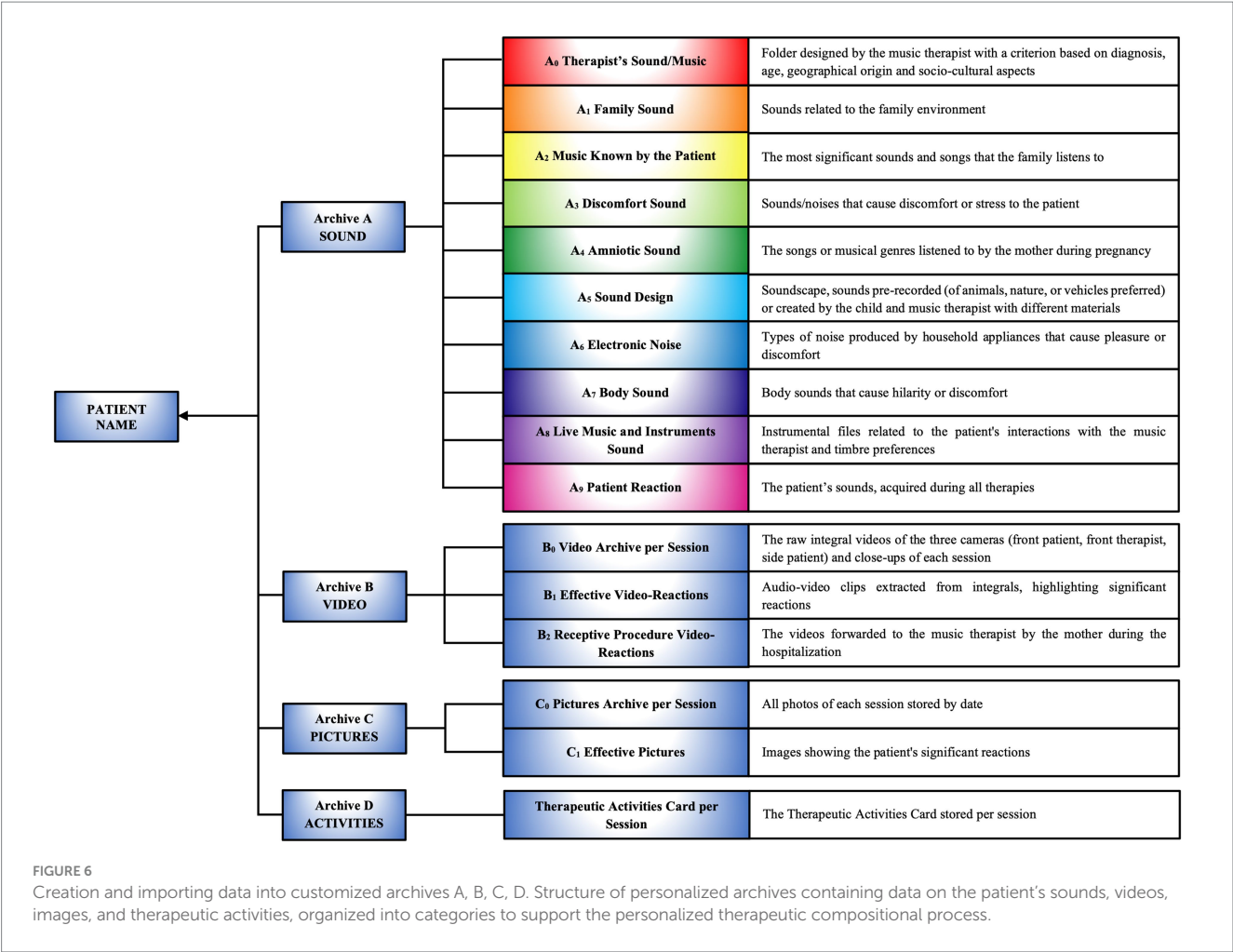
Phase A. Live Instrumental or Vocal has as its main objective the accurate monitoring of the patient's responses to assess his emotional and psychophysiological state. The therapist observes and documents every verbal and non-verbal response of the patient to establish a clinical baseline, which is essential for early detection of signs of discomfort or specific needs that may require targeted interventions. Therapy begins with silence, conceived as an active element (54),

intended to facilitate and promote the patient's adaptation within the therapeutic space.

This silence fosters concentrated attention and a gradual anticipation of auditory intervention, allowing the music therapist to establish initial non-invasive contact in a secure and trusting environment. Subsequently, the therapist uses the sound of their own breath, alternated with silence, to synchronize with the patient's breathing cycle, generating interest and attention. The music therapist introduces hand-clapping sounds, synchronized with the patient's breathing, and uses a sound level meter to identify the auditory threshold. At this stage, soft and warm vocal sounds, imitating the mother's voice, are emitted at an intensity of 30–35 dB. These sounds are used to initiate active interaction and modulate emotions in synchrony with the patient's heart rate and breathing variations (92–94).

Next, the real-time use of a musical instrument gradually introduces auditory stimuli with varying intensities, including consonant and dissonant intervals, glissandi, harmonics, and fragments of familiar songs or cartoon themes (95–98). The administration of such auditory stimuli often reveals significantly stronger responses in many patients when the clarinet is used. These patients exhibit a keen interest in following the sound trajectory in sync with the movement of the instrument, suggesting a deeper sensory and cognitive engagement in musical perception.

Additionally, it is noteworthy that the alternation between a familiar melody and intervals of silence induces predictive anticipation



of the melody's return in patients, suggesting an active expectation that predisposes them to emotional responses.

When the therapist introduces unfamiliar sounds, such as harmonics perceived as whistles, motor excitement and emotional surprise are observed, highlighting an innate curiosity toward new auditory stimuli. With controlled and repeated exposure to these sounds, patients develop progressive adaptation, demonstrating increased tolerance and predictive capacity, accompanied by moments of laughter. This process suggests sensory and cognitive adaptation, where acquired familiarity with unfamiliar sounds not only reduces initial surprise but also enriches the patients' emotional and social experience.

Supporting this, many studies highlight that the temporal dynamics of auditory signals contain significant information (99–103). The brain is thought to actively anticipate forthcoming auditory stimuli in consideration of prior contextual information; this process is known as predictive coding. This mechanism, essential for learning and language comprehension, as well as for musical processing of pitch and rhythm, has been extensively documented by various authors in audiology (104–111).

3.4.9 Reactions during listening

In this step, the music therapist manages and controls the Digital Audio Workstation to synchronize and adapt sounds in real-time to

the activities carried out by the co-therapist with the patient. This setup facilitates real-time musical composition and effective synchronization of therapeutic activities. The primary goal is to observe, evaluate, and understand the patient's reactions to novel auditory stimuli.

3.4.9.1 Choosing and playing a clip or track from archive a

If the patient does not exhibit any response during exposure to the audio clips, several possibilities should be considered:

- The musical stimulus may be inadequate for the patient's specific needs
- The patient's emotional or physical state may be influencing their responsiveness
- The patient may be disengaged or distracted
- A lack of response could suggest the need for further diagnostic evaluations for a more in-depth analysis.

3.4.10 CSI phase B. Sound stimuli processing

During exposure to new auditory stimuli, it is essential to adopt a sensitive therapeutic approach, particularly if the stimuli elicit negative reactions. In such cases, it is necessary to immediately cease sound administration and monitor the patient's responses, which may manifest through facial expressions, body movements, vocal tone

variations, or other signs of discomfort. If the negative stimulus stems from sounds or words essential to the patient, such as the mother's voice or natural sounds (soundscape), it is fundamental to process and adapt the sounds using appropriate techniques until acceptance is achieved. This issue is especially pertinent for long-term hospitalized patients who may experience alterations in sensory or relational learning (112).

Sound processing and modification techniques include amplitude adjustment, compression, delay, echo, and pitch correction. Key parameters for developing new real-time auditory stimuli that address the emotional and psychological needs of the patient include intensity, spatiality, directionality, speed, and frequency (Supplementary 3.4).

The therapist employs two playback methods to assess the efficacy of the sound stimuli: one involves the sequential presentation of processed musical clips, while the other overlays effective clips with unknown sounds.

The goal is to facilitate the acceptance of unfamiliar sounds, such as traffic and thunder, to improve quality of life and develop skills in managing environmental sound stimuli.

3.4.11 Archiving for implementing archive A

The music therapist extracts the patient's positive reactions from the raw audio recordings of the ongoing therapy. The acquired clips are timestamped, named according to content, and archived in the A₀ Patient Reactions folder. The process ensures that the therapist has immediate access to new sound material for use in the subsequent step of therapy.

3.4.12 CSI phase C. Administration of effective clips

In this phase, a sequence of auditory stimuli organized in *rhythmic patterns*, based on the patient's vocal reactions, is presented. The rhythmic patterns, designed as cyclic structures, regulate the temporal flow of music through the use of elements such as tempo, accents, rhythmic subdivisions, and meter (Figure 7I).

In the therapeutic context, these patterns serve as temporal organizers, facilitating the emergence and integration of the patient's vocal responses into repeatable models. Reproducing the patient's vocal reactions, structured within these patterns, enables the music therapist to verify the patient's ability to recognize their own voice, analyze the effects produced, and assess their skill in following the trajectory of the sound source.

This procedure acts as a tool for evaluating therapeutic efficacy and supports the patient's neurocognitive adaptation, promoting improvements in their ability to consciously recognize and reproduce their own voice.

In the following, new auditory stimuli specifically associated with congruent images are presented. An example of such correspondence would be the sound of a dog barking, synchronized with the display of an image depicting a dog. This technique aims to establish and enhance the synergy between visual and auditory processing, carefully modulating the relationship between image size and perceived sound intensity. Variables such as the distance of the sound source from the patient, the speed of sound approach or withdrawal, and the direction from which it originates are also considered. These factors are orchestrated to strengthen multimodal sensory connections, with the goal of fostering optimal sensory integration and a more coherent adaptive response from the patient, both

cognitively and perceptually. This assessment allows for the adaptation and modification of subsequent clips to optimize the therapy.

The treatment proceeds with the sequential or overlapping reproduction of clips to create a more complex, realistic, and engaging auditory experience that reflects the relationships between sound and environment.

3.4.13 CSI phase D. Personalized therapeutic composition

In the final phase of CSI, the music therapist integrates all positive effects observed in previous phases to create a PTC with logical continuity. The assessment of the patient's emotional, cognitive, and behavioral responses guides the therapist in the selection and organization of musical and textual elements, aligning with therapeutic goals.

The "perceptual hierarchical function" within the compositional structure of the PTC is configured as a mechanism for organizing and prioritizing sound materials based on the patient's positive responses. This process involves creating and managing a progressive sequence of compositional levels, which are continuously optimized and grouped according to their therapeutic efficacy. The hierarchical arrangement of sound elements, which include *sound cells*, clips, or compositional fragments such as individual voices (e.g., that of the patient, family members, or cartoon characters), is determined through a systematic analysis of the patient's recognition and responsiveness to such stimuli. This approach allows the music therapist to specify the order of appearance, progression, and overlapping of clips within the PTC, thereby optimizing therapeutic responses and achieving specific clinical objectives.

To represent and synthesize the interaction between auditory stimuli and patient responses, we have developed an iterative schema (Supplementary Figure 35; Figure 8; Supplement 3.5). This schema shows how an auditory stimulus and the patient's response merge to generate subsequent articulated stimuli. The goal is to create original and personalized musical sonorities, segments, and phrases based on the patient's positive reactions. The iterative process can be implemented in two modes: sequential (melodically) and simultaneously superimposed (polyphonically).

Horizontal iterative process (melodic)

In each horizontal iteration, an auditory stimulus (S_s) is presented to the patient. The patient's response (R_i) is fused with the original stimulus, resulting in a compound stimulus (Sc_i ; Figures 7E,F). This compound stimulus is archived and becomes the input for the next iteration.

Vertical iterative process (polyphonic)

The vertical iterative process is analogous to the creation of a polyphony, forming a complex set of stimuli to which the patient is invited to respond. The realization develops through overlapping stimuli administered simultaneously, such as $\{S_1(A_{0..s}) + S_2(A_{0..s}) + S_3(A_{0..s})\}$, fused with the patient's response (RV_i) to generate a new composite stimulus (ScV_i). This compositional technique is relevant as the patient's response not only reveals reactions to the stimuli but also provides valuable insights into the understanding and acceptance of the new auditory material presented (Figures 7G,H).

FILE TYPE	
Raw integral audio	A raw integral audio file of the mother's voice recording or a session recording with the patient (see Supplementary Figure 15).
Selected raw audio clip	An audio clip containing the patient's name, extracted from a raw integral (See Supplementary Figure 19).
Edited audio clip	Audio clips processed to eliminate background ambient noise using the following operations: Noise Reduction, equalization (EQ), Fade-in, and Fade-out.
	Example 1 Example 2 Example 3 Notation on stave Pitch spectrogram Waveform Frequency spectrogram Da - vi - de? Da - vi - de!
Processed audio clip	Example of audio clips processed for therapeutic purposes using primary effects such as reverb, noise generation, and remix. For additional examples, see Supplementary 3.3.
Region	Example of simple stimulus (Ss_1) and patient response (R_1) audio clips, consolidated into a single file (Sc_1) using the merge operation.
Horizontal Iterative Process	Ss_1 R_1 Sc_1
Track	Example of a track, resulting from the sum of unified regions containing horizontal composite stimuli ($Sc_1=Ss_1+R_1$, $Sc_2=Sc_1+R_2$, and $Sc_3=Sc_2+R_3$), through the Merge operation.
Vertical Iterative Process	$Sc_1=Ss_1+R_1$ $Sc_2=Sc_1+R_2$ $Sc_3=Sc_2+R_3$ $Sc_4=...$
Multitrack (PTC)	Example of a personalized therapeutic composition created from the patient's effective sound stimuli using horizontal and vertical iteration processes. The composition includes all the most effective clips, regions and audio tracks selected from Archive A for the therapeutic goal. Panel I Panel J
Mixdown	An example of a mixdown integrating all tracks from the multitrack into a single consolidated track. This mixdown track can then be overlaid onto other tracks in the multitrack.

FIGURE 7

This figure explicates the technical and compositional steps involved in creating and managing sound stimuli, integrating patient responses, and progressively developing a therapeutic pathway through iterative processing and personalized composition. Examples of vocal clip notations on the musical stave (A) alongside their pitch spectrograms (B), waveforms (C), frequency spectrograms (D). Consolidation of two sound clips, i.e., S_1 and R_1 (E), into a single new file (F). Consolidation of the Sc_1 , Sc_2 and Sc_3 clips (G) in the track (H). A rhythmic pattern focused of the patient's vocal reactions (I). Illustration of the PTC (Personalized Therapeutic Composition) processing within the software's multitrack interface (J). The track produced from the Mixdown process, showcasing the iterative and personalized approach to therapy through sound integration (K).

The compositional process continues through the use of harmony based on tonal intervals corresponding to the maternal voice spectrum. An example might be the use of a suspended cadence, where chords such as I-V or IV-II-V create a sense of questioning, perceived as expectation and tension. To reinforce and maintain this perception, a question pronounced by the mother's voice is inserted into the multitrack, superimposed on the suspended dominant chord. This arrangement serves to amplify the anticipatory tension inherent in the harmonic structure, thus engaging the patient's auditory and emotional process at a deeper level.

Subsequently, a silence interval is introduced to stimulate the patient's response. The sequence continues with a harmonic resolution, in which the dominant chord (V) resolves naturally over the tonic chord (I), creating a sense of predictability, relaxation, and conclusion. This harmonic resolution is further enriched through the integration of the patient's previous vocal reaction within the tonic chord, thus enhancing the effect of recognition and emotional gratification.

This compositional process aims to generate original sound material to be integrated into the PTC. The provided example shows one of many musical techniques designed to stimulate positive therapeutic responses, based on the patient's musical culture. It is essential to incorporate melodies and harmonies characteristic of the patient's musical tradition to maximize the effectiveness of the PTC.

Numerous studies demonstrate the effect of music on tone perception and sound environment, supporting iterative and compositional processes. In particular, tonal organization and its perception are central to the musical process (113). This concept is based on a tonal hierarchical structure that facilitates perception, memory, and musical execution, generating expectations in the listener (114).

Research conducted by Shepard and Jordan and Tillmann et al. provide empirical evidence demonstrating that listeners automatically use this tonal knowledge while listening (115, 116).

At the end of this phase, it can be confidently asserted that the sound material produced during sessions and all categorized sounds offer a wide range of possibilities for creating infinite PTCs.

Mechanisms of action of personalized therapeutic compositions

PTCs, based on personalized sound and musical stimuli, not only facilitate the interaction between the patient and parent but also exert a direct influence on numerous neurophysiological and psychological processes.

In the structure of the PTC, the perception of the maternal voice represents a fundamental component of infant development, influencing various aspects of the child's behavior and cognitive and emotional development (117–120). Elements such as the prosody of the child's name, positive reinforcement, and “motherese” are recognized for their positive impact on mood, motivation, and communication in therapeutic contexts (121–124). Previous studies have highlighted that listening to the recorded maternal voice elicits a complex response in the child, characterized by strong motor interest, contextual cognitive processing, and positive emotional response (36, 125, 126).

In motor terms, exposure to the maternal voice stimulates the child to orient toward the sound source, demonstrating active interest

in tracking the sound trajectory. This motor response suggests particular attention and sensitivity to the mother's voice, indicating an important foundation for the development of communicative and social skills.

From a cognitive standpoint, listening to specific words pronounced by the maternal voice within the musical structure of the PTC facilitates contextualization, meaning attribution, and content understanding for the patient. This phenomenon occurs through the combination of elements such as overlay of the maternal voice modulated to major chords, precise rhythmic patterns, evocative soundscapes of past experiences, and effective melody fragments. Such combination aids the child in navigating the sound space, facilitates memorization of auditory information, and allows understanding of emotional meaning contextualized within the surrounding environment. Furthermore, PTC combines sound stimuli with the patient's responses, contributing to the consolidation of neural pathways through an associative learning process. Regular repetitions within the PTC allow the brain to recognize and memorize sound patterns, thereby strengthening both short-term and long-term memory (127, 128).

From the emotive point of view, interaction with the maternal voice during the PTC induces a range of positive emotional responses in the child, including joy, empathy, and the desire to be embraced and supported. This emotional response indicates the quality and nature of mother–child interaction, highlighting the importance of affective bond in promoting emotional and social development of the child.

The mechanisms of action and effectiveness of the administration of PTCs could be traced back to the effects of music on the brain. Different studies provide evidence that MT has beneficial effects on functional brain activity and connectivity in networks underlying higher-order cognitive, socio-emotional, and motor functions. In fact, music perception can activate various limbic and paralimbic structures and improve network connectivity in children and adults (63, 64, 129). Music modulates synaptic plasticity and promotes neurobiological processes, neuronal learning, and readjustment in the human and animal brain (130, 131).

3.4.14 Session conclusion (n)

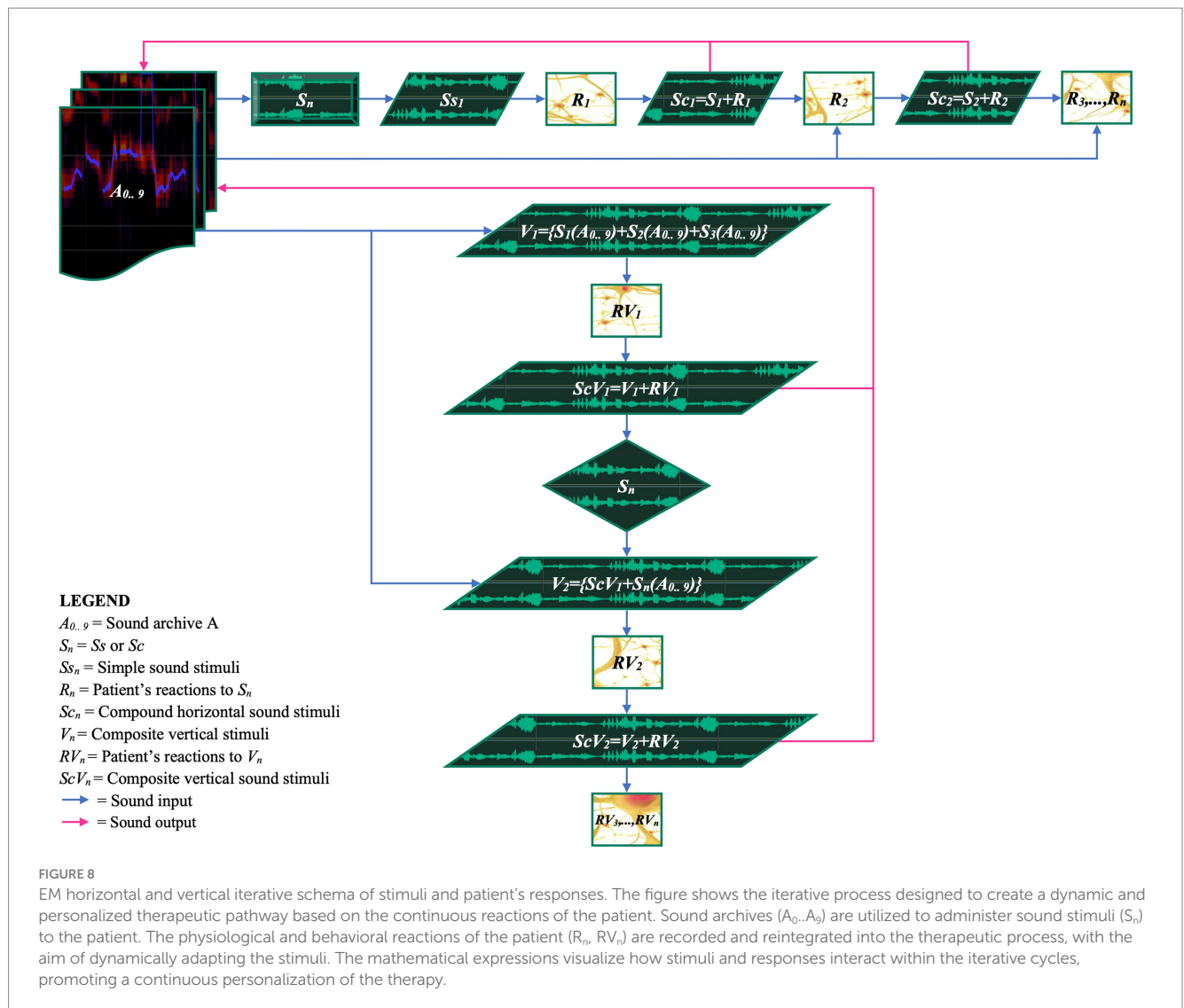
The conclusion of the therapeutic session is an important step for consolidating the work done and preparing both the patient and the parent for the continuation of the therapeutic path. This step is divided into three phases.

3.4.14.1 Step 1. Gradual inform the patient of session conclusion

The therapist signals to the patient, either verbally or non-verbally, the approach of the session's end, ensuring a gradual closure. This allows the patient to mentally prepare for the conclusion and to complete any communicative and emotional-relational needs.

3.4.14.2 Step 2. Sharing emerging changes with the parent

The therapist updates the parent on the changes or progress observed during the session, actively involving them and reinforcing the collaboration between the therapist and the family.



3.4.14.3 Step 3. Personalized “greetings” with the patient

The therapist concludes with personalized goodbyes, thanking the patient for their engagement and encouraging them for the work accomplished. This helps maintain a positive and motivating therapeutic environment.

3.4.15 Proceeding with EM receptive music therapy?

The receptive procedure, proposed by the rehabilitation team for pediatric patients with prolonged hospital stays, aims to compensate for the limited sensory and auditory exposure to the external world, thereby facilitating multisensory integration and supporting cognitive and emotional recovery.

The procedure is reported and detailed in Section 3.5 of the text and in Figure 3.

3.4.16 Extraction and archiving of audio clips and PTC in archive A

At the conclusion of the therapeutic session, the music therapist extracts audio tracks from the devices used (Supplementary 3.2). The most relevant clips are selected and archived in Archive A for future

reference. Additionally, the intermediate PTC is archived for use in subsequent sessions.

3.4.17 Extraction and archiving of audiovisual files in archive B

The therapist extracts and catalogs raw session material into the folder “B₀ Video Archive per Session,” organizing it by date. The footage is then reviewed, edited into shorter clips, and archived in the folder “B₁ Effective Video-Reactions” to monitor significant changes in patient behavior. Additionally, video feedback from patients completing EM Receptive or EM Telerehabilitation procedures is chronologically archived in the folder “B₂ Receptive Procedure Video-Reactions.”

3.4.18 Extraction and archiving of pictures in archive C

Images extracted from session videos are stored in the folder “C₀ Picture Archive per Session.” The most relevant photos, selected based on session activities, therapeutic goals, and emotional states, are transferred to the folder “C₁ Effective Pictures” to document clinical progress and new learnings.

This process enables the creation of the Audiovisual Soundtrack (AVS) for home therapy protocols, as indicated by Bompard et al. (35).

3.4.19 Compilation and archiving of therapeutic activity card in archive D

This document summarizes the activities performed during each session, the materials used, relevant musical bibliography, the tonalities employed, and the patient's responses. It provides a useful overview for a detailed evaluation of therapeutic practices and patient responses, aiding in the adaptation and refinement of therapeutic strategies (Supplementary Figure 14).

3.5 EM receptive procedure

The EM Receptive intervention, prescribed by the hospital team, is implemented during the hospitalization, targeting pediatric patients in early developmental stages or those undergoing prolonged hospital stays. These children often experience limited exposure to sensory and auditory stimuli, which can potentially hinder their neurocognitive development (112). The intervention aims to compensate for this lack by optimizing well-being through auditory stimulation tailored to the therapeutic goal.

The EM Receptive procedure unfolds in a series of phases, grounded in a continuous monitoring model and dynamic adjustment (Figure 3).

3.5.1 Initiation of the EM receptive program

The therapeutic path begins with a retrospective analysis of the patient's previous sessions during hospitalization, aimed at identifying sensory gaps, deficits, and issues. This initial evaluation allows for the customization of compositional sound interventions, thereby optimizing learning and enhancing receptivity to maximize the rehabilitative process's effectiveness.

3.5.2 PTC creation

Based on the information gathered, the sound clips most relevant to the patient are selected. A PTC is then created, designed to stimulate emotional and cognitive responses by the use of soundscapes and everyday auditory stimuli. Audio materials are chosen according to the patient's "*perceptual hierarchical function*" and enriched with novel and unfamiliar sounds essential for the patient's life.

The final file, exported in MP3 format and accompanied by a technical sheet containing detailed instructions for administration, is provided to the family. The parent assumes responsibility for managing the PTC following the provided guidelines.

3.5.3 PTC administration

The PTC is administered via a Bluetooth speaker, operated by the parent, with sound intensity regulated between 40 and 50 dB. Therapeutic sessions take place in the afternoons without active MT, during which the PTC is proposed three times at two-hour intervals. This schedule not only promotes the assimilation of auditory experiences but also ensures adequate recovery between exposures. These intervals allow for careful monitoring of the patient's emotional and cognitive responses, facilitating therapeutic adjustments when necessary. The PTC has a length of approximately 2–3 min, a time designed to maintain the child's attention and optimize therapeutic

outcomes, while avoiding sensory overload. During the administration, the parent video records the child's reactions.

3.5.4 Feedback collection and transmission

The parent sends the video feedback to the music therapist, who archives the material in the patient's B₂ folder. This system consents a systematic monitoring of the child's responses to the musical intervention and facilitates a comprehensive evaluation of the PTC's effectiveness.

3.5.5 Feedback analysis and adaptation

The music therapist reviews the video feedback, focusing on the patient's sensory and behavioral responses during listening sessions of the PTC. This analysis enables the evaluation of the impact of the proposed sounds and allows for targeted modifications to the musical composition based on the observed reactions.

These adjustments stimulate neural circuits related to auditory processing and emotional regulation, promoting the reorganization of neural networks (132). This process optimizes the integration of auditory experiences, enhancing the patient's responsiveness. Continuous feedback enables the therapist to further refine the intervention, ensuring a progressively more personalized and effective therapeutic approach.

3.5.6 Interaction and integration with EM active

Information collected through the EM Receptive procedure is utilized to improve active MT sessions. The reactions observed during receptive administrations provide the therapist with insights to refine the EM Active intervention, maximizing the overall therapeutic efficacy.

3.6 EM telerehabilitation procedure

EM Telerehabilitation, prescribed by the hospital team or requested by parents, enables discharged patients to continue MT at home (Figure 4).

The goal of EM Telerehabilitation is to ensure the continuity of the rehabilitation process within the home environment. This therapy not only preserves the progress obtained but also stimulates further improvements, adapting to the patient's developmental needs and home context. Additionally, the importance of telerehabilitation lies in its ability to reach areas where rehabilitation facilities are limited or absent, thus providing treatment opportunities for patients in remote locations (133).

The music therapist initiates the EM Telerehabilitation process by reviewing the patient's clinical documentation, which is fundamental for customizing the intervention.

The technical process begins with a detailed analysis of the patient's database, which includes the personalized archives generated during hospitalization and EM MT activities. In this initial phase, recorded audio-video clips are evaluated, focusing on patient reactions, particularly reaction times and attention levels. Detailed analyses of musical bibliography and personalized music are conducted to identify those that have demonstrated the greatest therapeutic efficacy.

From this data, a detailed graph is created to provide an overview of the MT path made (Supplementary 4).

Next, a PTC is composed according to the specific treatment goals. In addition, significant videos and images documenting key moments of the patient, such as smiles, interactions, and activities stimulated by MT interventions during hospitalization, are extracted from Archives B and C. These elements are then overlaid onto the PTC using video editing software to create an Audiovisual Soundtrack (AVS). The technical criterion for overlaying images and videos is based on the alignment of significant moments experienced by the patient (e.g., expressions of joy and participation) and the PTC music. This approach allows for synchronizing the patient's emotional and behavioral reactions with the PTC's acoustic features.

The duration of AVS generally ranges from 3 to 4 min and is tailored to the patient's specific treatment goals.

Once the AVS is completed, the music therapist instructs the family on administration procedure using a technical sheet that details timing and methods.

The AVS should be administered using an appropriate device, preferably a television, for 12 consecutive days. The protocol involves three daily sessions, with the final session scheduled at least 3 h before bedtime. A 24-h break is also included on the seventh day. Sessions, scheduled from early afternoon and spaced at least 2 h apart, accommodate family commitments.

The parent administers the treatment to the child, involving, when possible, the entire family in active MT activities.

During AVS administration, the parent documents the patient's responses by sending video feedback to the music therapist for continuous monitoring and potential technical adjustments. These files are archived by the therapist to monitor treatment evolution and adapt the intervention to the patient's emerging needs.

The AVS, combining images and videos with the PTC, creates a personalized short film where the patient is the protagonist. This approach enhances therapeutic efficacy, significantly improving the patient's emotional and motivational engagement.

EM Telerehabilitation has shown statistically significant results in sleep disorders and reducing parental stress (35).

3.7 Participants

The study by Bompard et al. included 20 children with developmental delay who had participated in the EM program prior to the pandemic. Of these, 12 completed all home sessions and assessments and were therefore eligible for data analysis (35).

The subsequent research, by Liuzzi et al., selected 58 children from a larger cohort, randomized into an experimental group ($n=35$) and a control group ($n=23$); among these, 25 children in the experimental group and 10 in the control group completed assessments at both T0 and T1 (36).

The procedures were conducted in accordance with the Declaration of Helsinki, with informed consent obtained from the parents.

3.8 Measures

The measures adopted in the study by Bompard et al. (35) included the Sleep Disturbance Scale for Children (SDSC), used to

assess sleep quality (134), and the Parenting Stress Index - Short Form (PSI-SF), employed to analyze parental stress (135). In the subsequent research by Liuzzi et al. (36), additional assessments were introduced, including the Italian Questionnaires of Temperament (QUIT), which investigates the child's behavior in various social and play contexts (136), and the Pediatric Quality of Life, which explores the quality of life of children through age-specific modules, also including the Family Impact Module intended for parents (137–139).

3.9 Statistical analysis

The data from the first feasibility study of EM were analyzed using MedCalc software, version 12.7 (MedCalc Software, Belgium). Categorical variables were reported as absolute numbers and percentages, while continuous variables were expressed as median and standard deviation if normally distributed, assessed using the D'Agostino–Pearson test. Differences in pre- and post-treatment measures were examined using the paired t-test. A two-tailed p -value <0.05 was considered statistically significant (35).

For the second study, statistical analyses were conducted using STATA software, version 17 (StataCorp LP, College Station, TX). Data normality was assessed using the Shapiro–Wilk test. Categorical variables were summarized in absolute frequencies and percentages, while continuous variables were expressed as mean and standard deviation. To determine statistical differences in scores between baseline (T0) and post-treatment (T1), the paired t-test was used for continuous variables. Additionally, scores between subjects in the experimental group and the control group were compared at both baseline and post-MT using the independent t-test, while categorical variables were compared using the Chi-square test or Fisher's exact test. Statistical significance was set at $p < 0.05$ (36).

4 Results

The application of EM resulted in significant improvements across various key areas for children with neurodevelopmental disorders. Previous studies have provided relevant statistical evidence regarding the positive effect of EM on sleep quality, emotional regulation, and the reduction of parental stress (35, 36). We reiterate previous data to support the analysis of the results obtained, thereby consolidating the evidence of EM's effectiveness. This integration strengthens the evaluation of the observed improvements in key areas, providing a solid comparative basis for the current study.

4.1 Children

In the study by Bompard et al. (35), a statistically significant improvement in sleep quality was recorded. The total score on the SDSC decreased from 49.5 ± 19.7 to 40.5 ± 10.5 ($p=0.010$), indicating an overall improvement. Specifically, sleep breathing disorders dropped from 6.5 ± 3.6 to 4.4 ± 2.7 ($p=0.012$), and sleep–wake transition disorders improved from 10.6 ± 4.7 to 8.8 ± 2.8 ($p=0.032$). These findings were confirmed by Liuzzi et al. (36), who observed a statistically significant reduction in the total score on the SDSC from 42.4 ± 14.5 to 37.7 ± 12.7 ($p=0.031$). Additionally, disorders related to

the initiation and maintenance of sleep decreased from 14.6 ± 7.1 to 13.4 ± 6.1 ($p=0.050$), while sleep–wake transition disorders further improved from 9.6 ± 3.3 to 8.0 ± 2.9 ($p=0.026$).

Furthermore, concerning emotional control, Liuzzi et al. (36) noted a statistically significant increase in the positive emotionality score of the QUIT, rising from 4.1 ± 1.4 to 4.4 ± 1.2 ($p=0.013$), demonstrating the effectiveness of EM in emotional regulation.

4.2 Parents

Bompard et al. (35) show a statistically significant reduction in parental stress. The PSI-SF score related to parental distress decreased from 27.4 ± 10.1 to 24.4 ± 10.2 ($p=0.001$), accompanied by an improvement in defensive responding, which fell from 16.8 ± 5.9 to 14.8 ± 6.3 ($p=0.012$).

Finally, the study by Liuzzi et al. (36) reported statistically significant improvements in family quality of life as measured by the Pediatric Quality of Life, with the emotional functioning score increasing from 61.6 ± 26.4 to 69.6 ± 22.6 ($p=0.029$), and social functioning improving from 61.5 ± 25.4 to 68.3 ± 26.4 ($p=0.012$). Statistically significant improvements were also recorded in worry ($p=0.032$), daily activities ($p=0.032$), total score ($p=0.039$), and health-related quality of life ($p=0.035$), highlighting the positive impact of EM on the entire family.

5 Critical analysis

5.1 Ethical considerations in integrating music technology with neuroscience

The integration of music technology with neuroscience in therapeutic contexts raises significant ethical issues. A fundamental aspect concerns informed consent, which is particularly important when working with vulnerable populations, such as children.

It is essential for therapists to ensure that patients and their caregivers have a full understanding of the interventions, the use of technology, and any potential risks involved (140). This transparency is essential for maintaining trust and guaranteeing the autonomy of participants.

Moreover, privacy protection and data security are imperative when using technologies that collect sensitive patient information. Such data must be anonymized and securely stored in accordance with the General Data Protection Regulation (141), to ensure patient confidentiality.

Lastly, there is a risk of biases and inequities in access to music technology. Therapists need to be aware of cultural, socioeconomic, and individual differences that may influence how patients respond to music technology. Ensuring equitable access to MT that is culturally sensitive is critical for optimizing therapeutic outcomes for all patients (142, 143).

5.2 Neuroscientific considerations

The interdisciplinary approach that integrates MT with neuroscience provides an in-depth understanding of the

neurobiological mechanisms underlying music's influence on brain function and behavior. Neuroimaging studies consistently demonstrate that MT engages various brain regions responsible for emotions, cognition, and motor functions. Research has highlighted that music can stimulate neuronal plasticity, enabling the brain to form new neural connections, a relevant aspect for rehabilitation and cognitive development (63, 64, 132, 144).

Furthermore, MT facilitates the release of neurochemicals such as dopamine, associated with pleasure and reward, and endorphins, which contribute to pain reduction (49, 132). An additional relevant aspect is that music modulates cortisol levels, helping to reduce stress and anxiety (145).

However, while the benefits of MT are clear, it is also essential to investigate and acknowledge the potential risks.

5.3 Potential risks and limitations

Integrating music technology into therapeutic practices, while offering notable advantages, presents risks and limitations, particularly for vulnerable populations like children.

5.3.1 Sensory overload

One major concern is the risk of sensory overload, especially in children with neurological disorders or heightened sensory sensitivities. Complex and intense musical stimuli can lead to confusion and discomfort, particularly in children with autism spectrum disorder (146, 147).

5.3.2 Elicitation of unwanted memories

Music has the potential to evoke painful memories, which can be particularly distressing for children with past traumatic experiences (148, 149).

5.3.3 Physical injuries

MT activities involving movement or dance may carry the risk of physical injuries. Children with motor impairments are especially vulnerable to falls or injuries if the activities are not adequately supervised and adapted to their physical capabilities (150).

5.3.4 Privacy and data security

Collecting and archiving sensitive patient information requires particular attention to ensure privacy and data security. It is fundamental to ensure that data is securely stored and anonymized, adhering to regulations such as the General Data Protection Regulation (141).

5.3.5 Economic disparities

Music technologies for electronic composition can be expensive, limiting access to services in economically constrained settings. Ensuring equitable access to MT resources is essential to reduce disparities (151–153).

5.3.6 Photosensitivity and epilepsy

Multisensory environments, including visual stimuli, may trigger seizures in children, particularly those with epilepsy. Adapting the therapeutic environment to avoid such triggers is essential (154).

5.3.7 Age-related considerations

Age-specific factors influence session duration and frequency. Younger children may require shorter, more frequent sessions, while older children may benefit from longer, structured sessions (155).

5.3.8 Technological complexity and accessibility

The complexity of music technologies can limit access, especially in under-resourced settings. Over-reliance on technology may also reduce direct human interactions (153, 156).

5.3.9 Psychological implications and emotional challenges in recording the maternal voice

The recording of the maternal voice, essential in the EM MT intervention, may induce significant discomfort in the parent. This discomfort often stems from the embarrassment of singing in front of others and the challenges of meeting the specific technical demands set by the music therapist. The intimate nature of the process, which requires the use of the voice in a highly structured context with high technical expectations, accentuates these challenges. This process can trigger intense emotions, with reactions such as crying, further complicating the recording. To manage the parent's stress and emotions, coping strategies are fundamental. An empathetic and supportive approach, including emotional validation and relaxation techniques, can create a more serene therapeutic environment. Additionally, gradual preparation and the use of mindfulness can help parents focus on the present, alleviating anxiety and improving the quality of the therapeutic interaction. These measures not only adhere to ethical principles but are also essential for optimizing treatment efficacy (157).

5.3.10 Challenges for the training of music therapists in the Euterpe method

The effective implementation of the EM requires highly specialized therapists trained in MT, neuroscience, and musical technologies. This necessity may limit the availability of qualified professionals, particularly in resource-limited areas. Furthermore, the ongoing advancement of musical technology and therapeutic techniques necessitates continuous education and training, creating potential barriers for new professionals entering the field. Therefore, it is essential to develop interdisciplinary training programs and continuing education pathways that ensure adequate preparation and equitable access to training for therapists.

6 Ethical considerations

In conducting pediatric research, it is essential to implement rigorous ethical protocols to manage power dynamics and protect the rights of participants. We ensured the active involvement of children and parents, fostering a collaborative and respectful environment. Informed consent was obtained from parents, ensuring they were fully informed about the research objectives, procedures, and potential risks.

During the MT sessions, safety measures were adopted to protect participants by monitoring and adjusting therapeutic activities based on their reactions. The confidentiality of data was assured through anonymization and restricted access to sensitive information.

Additionally, the active participation of children was emphasized, respecting their autonomy and individual preferences.

The research team engaged in professional supervision and critical reflection sessions to address ethical issues and ensure that therapeutic decisions adhered to the highest standards of integrity. This approach ensured that therapeutic practices not only respected the ethical principles outlined in the Declaration of Helsinki but also contributed to improving the quality of life for patients while maintaining high standards of scientific and human responsibility.

7 Discussion

The EM approach presented in this study represents an innovative integration of musical sciences, MT, and pediatric care. Through the use of electronic compositions and multisensory environments, a marked improvement in therapeutic outcomes emerges, specifically addressing the needs of pediatric patients. Technology allows for real-time adaptability, making treatment flexible and dynamic while optimizing therapeutic procedures.

Our previous studies (35, 36) have demonstrated the effectiveness of the EM approach, highlighting tangible progress in emotional regulation and sleep quality in children, as well as reductions in parental stress and improvements in family quality of life.

The multisensory integration has further enriched the intervention, enabling a more comprehensive response for patients with specific needs, such as those with disabilities or sensory disorders. The personalization of musical compositions has enhanced patient engagement, promoting autonomy and self-esteem.

Active involvement of parents has made the intervention even more effective. The adoption of techniques in daily family routines has strengthened the parent-child bond and improved treatment efficacy without requiring specialized training for caregivers.

The analyses by Paterson et al. and Le Vu et al. (39, 41), which examined our studies (35), emphasized the importance of the replicability of the EM protocol and its capacity to respond to emerging medical needs, such as telerehabilitation. This article rigorously addresses these aspects, proposing algorithms to ensure effective methodological application, even remotely.

Moreover, the use of multisensory therapeutic environments has shown strong potential in improving patient communication and participation, facilitating pediatric rehabilitation within an integrated sensory stimulation context.

This study demonstrates how the integration of medicine, neuroscience, and MT through the EM approach can significantly enhance the well-being of pediatric patients and their families. Furthermore, the results suggest new directions for developing increasingly personalized and interdisciplinary clinical interventions.

8 Implications for practice

8.1 Clinical applications

The findings of this study reveal significant implications for a wide range of clinical and institutional settings. EM represents a highly detailed non-pharmacological intervention that integrates innovative

technologies and personalized compositions, both pre-programmed and real-time, to address the specific therapeutic needs of patients. This innovative approach is particularly suited to enhancing patient care across diverse settings, promoting emotional and psychophysiological health and well-being.

8.2 Key application contexts

EM can be applied in a variety of settings, including pediatric hospitals, rehabilitation centers, psychiatric institutions, facilities for degenerative diseases, post-stroke rehabilitation units, oncology and palliative care centers.

8.3 Neurobiological mechanisms

The integration of multisensory stimulation, a key element of EM, interacts with the central nervous system, promoting neurobiological regulation that supports neuroplasticity and functional recovery. Recent studies have shown that multisensory stimulation activates distributed neuronal networks, facilitating sensory information integration and enhancing modulation of the patient's emotional and cognitive states. Specifically, the combination of visual, auditory, and tactile stimuli can enhance synaptic plasticity in higher cortical areas, contributing to improvements in cognitive and motor skills (63, 64, 71, 132, 144, 158).

EM may also positively influence neuropsychological circuits involved in anxiety regulation and stress management, increasing therapeutic efficacy while reducing the need for pharmacological interventions (132, 145).

These mechanisms underscore EM's importance not only as a tool for physical rehabilitation but also as an intervention for managing emotions and promoting psychological well-being.

8.4 Case study 1: Pediatric hospitals and rehabilitation centers

In a pediatric hospital, a seven-year-old child with cerebral palsy manifested emotional dysregulation toward his mother, evidenced by marked emotional indifference and intolerance to the mother's voice. A significant change was observed after 3 weeks of EM treatment. The mother-child relationship showed remarkable improvement, with increased affective interaction and a richer emotional response from the child. This suggests that EM is effective in promoting psychological well-being and improving relational dynamics, facilitating affective interactions and emotional communication between child and mother (36).

8.5 Case study 2: Oncology centers and palliative care

In an oncology center, a six-year-old girl with leukemia benefited from EM MT in reducing anxiety and managing pain during chemotherapy. The combination of MT with a multisensory environment significantly improved her mood and general well-being, highlighting EM's potential in integrated therapeutic support (159).

8.6 Future research and perspectives

To further optimize EM, focused research on sensory integration mechanisms is essential, exploring the impact of orchestral therapy on cognitive function, motor skills, and social inclusion. Orchestral therapy, in particular, offers opportunities to improve discipline, responsibility, and teamwork, with positive effects on neuroplasticity and social integration, reducing isolation and promoting emotional well-being (160).

EM is confirmed as an innovative and resilient therapeutic approach that extends MT's applicability to complex clinical settings. Its ability to synergistically integrate with other therapeutic modalities and its customizable adaptability throughout the treatment pathway constitute a substantial advancement in improving patients' quality of life.

9 Conclusion

The integration of neuroscience, music, and technology has led to the development of personalized therapeutic interventions, emphasizing the importance of an innovative approach in pediatric rehabilitation.

The EM approach has proven effective in improving critical aspects of children's health, including sleep quality, emotional regulation, and reducing parental stress, contributing to the overall well-being of the families involved.

The combination of personalized electronic compositions with multisensory environments has enhanced the effectiveness of treatment, leading to more significant outcomes. Moreover, the active participation of parents has been an essential factor in the rehabilitation process, improving engagement and the efficacy of therapies.

The results obtained provide important practical implications for the replicability of the EM approach in clinical settings, suggesting that its application can enrich pediatric rehabilitation programs. The findings of this study not only expand the understanding of MT in treating developmental disorders but also lay the groundwork for further research in the field, aiming to explore its efficacy and establish clinical practice guidelines.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding author.

Ethics statement

The requirement of ethical approval was waived by Bambino Gesù Children's Hospital, IRCCS, Rome, Italy for the studies involving humans due to the methodological nature of this article. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the minor(s)' legal

guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

TL: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. FD'A: Investigation, Visualization, Writing – original draft, Writing – review & editing. MR: Funding acquisition, Supervision, Writing – review & editing. PB: Writing – review & editing. MT: Writing – review & editing. RG: Writing – review & editing. EC: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fneur.2024.1443329/full#supplementary-material>

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Parental singing during kangaroo care: parents' experiences of singing to their preterm infant in the NICU

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Introduction: Singing fosters emotional connections, attachment, bonding, and language development in infants. Prematurely born infants, however, are at risk of missing this vital communication, impacting neurodevelopment and family wellbeing, especially during prolonged hospital stays. Kangaroo care provides physiological and emotional support, while Creative Music Therapy (CMT) has demonstrated positive effects on neurodevelopment, parental wellbeing, and attachment. The Singing Kangaroo project, a Swedish-Finnish multi-center randomized controlled trial (RCT), investigated the impact of parental singing during kangaroo care. This qualitative follow-up study explores these findings through the lens of Antonovsky's Sense of Coherence (SOC) model.

Method: Semi-structured interviews were conducted with 28 families (20 intervention group, eight control group) at their infant's 5-month corrected age. The intervention group received CMT twice weekly during kangaroo care for 4 weeks in the NICU, while the control group received standard care. Data were analyzed inductively, followed by deductive categorization within the SOC framework, focusing on its three core components: Manageability, Comprehensibility, and Meaningfulness.

Results: Parents in the intervention group reported enhanced understanding of how singing fosters attachment and boosts their self-esteem, aligning with increased manageability and comprehensibility. Control group parents also experienced joy in singing, which positively influenced family wellbeing, albeit less extensively. Across both groups, singing was described as a meaningful activity that strengthened parent-infant bonding and promoted emotional connection within the family.

Conclusion: Parental singing during kangaroo care, particularly when supported by a trained music therapist, enhances parents' sense of coherence by fostering comprehensibility, manageability, and meaningfulness. This study highlights the long-term benefits of integrating CMT into family-centered NICU care to support both infants' neurodevelopment and family wellbeing.

KEYWORDS

emotional attachment, kangaroo care, music therapy, NICU, parental singing, patient and family centered care, preterm infant

1 Introduction

Most of the time it's just joy, like, that I want to draw out laughter from him and sing when playing, but I also feel a lot of closeness. When I sing lullabies, I feel very strong feelings of closeness and love and tenderness. It becomes like a way to hold him in a different way, you like hold him with music. You embed yourself in the lullaby!

Mother from the intervention group

All over the world, parents sing to their infants in all known cultures. It is a way for infants and parents to connect emotionally when building relationships. Parents use their voices in different ways; they sing, hum, vocalize and use their voice in smooth and soft melodic small talk, so-called infant-directed speech, when communicating with their infants (Bonnár, 2014; Sharman et al., 2023). The infants interact in non-verbal communication via movements, gestures, facial expressions and sounds (Malloch and Trevarthen, 2018). *Communicative musicality*, as described by Malloch and Trevarthen (2009), refers to the delicate and intimate exchanges between infants and their parents. This form of communication is essential for parent-infant interaction, supporting attachment—the emotional connection that develops over time through consistent care—and bonding, the immediate emotional tie formed shortly after birth. Such interactions are fundamental for fostering secure attachment and strengthening the parent-infant bond (Beebe, 2017; Trevarthen, 1999). Furthermore, early reciprocal communication, enhanced by musical elements, plays a crucial role in the infant's socio-emotional development and lays the foundation for early language acquisition (Falk and Audibert, 2021; Jaffe et al., 2001).

Regarding premature-born infants, attachment, bonding, and language development can be suppressed. Preterm infants are at risk of neurodevelopmental (Pascal et al., 2018), language (Vandormael et al., 2019) and cognitive developmental impairments (Aarnoudse-Moens et al., 2009). The parents are confronted with psychosocial challenges during their often long-lasting hospital journey (Galea et al., 2022). These challenges can compromise their intuitive parenting skills and their ability to provide their fragile infant with the intimate closeness and safety that only they, as parents, can give (Flacking et al., 2012; Sanders and Hall, 2018). In addition, preterm infants' social behavior is still immature, and infant cues are much harder to understand than in full-term babies, which may suppress the natural parent-infant-interplay as well (Porges, 2011).

A way to address both infants' and parents' needs is to provide developmentally supportive child and family-centered care. This way of caring for the families in the neonatal intensive care unit (NICU) has become standard in many countries worldwide. It strives to put the family at the center of care and the infant at the center of the family (Bronfenbrenner, 1979; Darling, 2007; Kuo et al., 2012; Kutahyalioğlu and Scafide, 2023). An essential part of this is kangaroo care, which supports the infant's physiological needs but also the emotional needs of both the baby and the parents (Clarke-Sather et al., 2023; Narciso et al., 2022; Pathak et al., 2023). It gives the infant direct access to the parent's bare chest, heartbeat, breathing, smell, warmth, vibrations from the

bone construction, and the parents' voice. It has been shown to stabilize the preterm-born infant's respiratory rate, oxygenation and temperature and to support breastfeeding (Boundy et al., 2016). Furthermore, kangaroo care is associated with reduced maternal depression and anxiety and improved parental wellbeing, bonding and attachment (Pathak et al., 2023).

Singing and speaking during kangaroo care seem to be one of the most natural ways to connect and communicate between infant and parents (Filippa et al., 2017; Hugoson and Eulau, 2023). Indeed, parents sing and use their voices when interacting with their preterm infant in the NICU if they feel it safe to do so (Shoemark and Arnup, 2014). Parental singing during kangaroo care may improve the infant's autonomic stability and decrease maternal anxiety (Arnon et al., 2014; Kostilainen et al., 2020). Further, it has been associated with enhanced auditory development, an integral part of early language development (Kostilainen et al., 2021; Partanen et al., 2022). Parents experiences of singing to their preterm infant in the NICU have been shown to have a positive impact on shaping parental identity, meeting parents' emotional needs and acting as a way for parents to connect with their infant (Ettenberger et al., 2016; Ghetti et al., 2021; McLean, 2016; McLean et al., 2018; Palazzi et al., 2020). Notably, the music therapy method Creative Music Therapy (CMT) is associated with improved neurodevelopment in the infant (Haslbeck et al., 2020), parental wellbeing and fostered attachment and bonding between the preterm infant and the parents (Haslbeck, 2014; Haslbeck et al., 2021; Kehl et al., 2021).

Creative music therapy with preterm-born infants and their parents (CMT) is a family-centered resource and needs-oriented, well-established and researched music therapy method (Haslbeck and Bassler, 2020). A certified music therapist gently supports the infants' need for a sensitive, sensory, meaningful experience and the parents' need to communicate interactively with their preterm infant. The aim is to strengthen the intuitive capacities of parenting by supporting and empowering the parents in an undemanding and relational therapeutic approach while sharing the experience of the infants' expressions here and now guides the dialogue between parents and the music therapist.

1.1 Singing kangaroo study

In an ongoing multi-center study, the Singing Kangaroo, Finnish and Swedish researchers explored the potential benefits of parental singing on the language and neurodevelopment of prematurely born infants, as well as the impact of parental singing on the wellbeing of the families (ClinicalTrials.gov ID NCT03795454). In the Finnish cohort, positive results of parental singing have been found regarding maternal wellbeing, early mother-infant relationship and early auditory discrimination of speech sounds in the infants (Kostilainen et al., 2020, 2021).

The Swedish cohort began by conducting a randomized controlled trial (RCT) assessing the impact of parental singing during kangaroo care on auditory processing of standardized audio stimuli using magnetoencephalography (MEG) at term-corresponding age (Partanen et al., 2022). Preterm infants (born between 24 and 32 weeks of gestation) admitted to the NICU were

randomly assigned to the singing intervention group or the control group. The intervention group, implementing CMT, received gentle support from a qualified music therapist twice a week for 4 weeks, to sing or hum in an infant-directed manner during kangaroo care. The control group received standard kangaroo care. Both groups documented their singing frequency and duration throughout the day and night in diaries, collected weekly by the music therapist, fostering ongoing communication. The design of the diaries was based on the one used by Raiskila et al. (2017), with an added parameter for parental singing.

The MEG findings indicate that infants in the singing intervention group exhibit larger neural responses to changes in speech sounds compared to those in the control group, even when accounting for the overall amount of singing during kangaroo care in both groups (Partanen et al., 2022). These results, in conjunction with the potential impact of CMT on positive parenting, meaningful interactions, empowerment, improved parental self-esteem, and enhanced caregiver sensitivity studied by Haslbeck (2014) and Haslbeck et al. (2021), raise questions concerning potential positive outcomes on the whole family when incorporating parental singing, gently supported by a qualified music therapist, into kangaroo care.

In light of the potential of CMT to mobilize parental resources, facilitate meaningful interactions, and promote parental empowerment, the concept of coherence emerged during the initial discussions between the first and last authors. When meeting major life events such as preterm birth, it is essential to find ways to manage the situation. Antonovsky (1979) presented the concept of *sense of coherence* (SOC) as a way of understanding how people undergoing stressful and potentially traumatic experiences can mobilize their resources. Sense of coherence consists of three key components: comprehensibility, manageability, and meaningfulness. Comprehensibility is the cognitive component that refers to how the individual takes in and understands the information given. Manageability is the component that refers to how the individual perceives whether their resources available are sufficient or not. Meaningfulness refers to the motivational component i.e., the extent to which the individual feels what they experience is worth it. These three components interact and are all needed to create a sense of coherence (Moksnes, 2021).

With a focus on parents' experiences and aiming for a deeper understanding of the mechanisms involved in the observed outcomes in Partanen et al. (2022), we proposed a qualitative follow-up study to further explore and unpack the benefits of parental singing in relation to the concept of coherence. Therefore, the aim of this study, as part of the Swedish cohort of the Singing Kangaroo project, was to explore the potential influence of CMT in the NICU on enhancing the sense of coherence in parents as they engage in singing to their preterm-born infants during kangaroo care in the NICU. The research questions arose about how the parents experience singing for their preterm-born infant during kangaroo care and whether CMT may influence the parental sense of coherence?

2 Method

This study adopts a qualitative interpretative design, utilizing a phenomenological hermeneutical method (Lindseth and Norberg,

2004) inspired by Ricoeur (1976), and grounded in a hermeneutic philosophical framework (Patton, 2015). The method integrates the life-world philosophy of phenomenology with the hermeneutic tradition of text interpretation to illuminate the meanings of lived experiences. These experiences, while inherently individual, were interpreted from interviews transcribed into autonomous text, enabling an understanding and explanation of human phenomena (Ricoeur, 1976; Lindseth and Norberg, 2004).

The analysis was conducted using a manifest inductive qualitative content analysis (Elo and Kyngäs, 2008), emphasizing the interpretative nature of understanding human experiences. Semi-structured interviews were conducted with parents from two groups: an intervention group, who participated in the CMT (Creative Music Therapy) program, and a control group, who received standard care (Kvale and Brinkmann, 2009). The methodology combined inductive reasoning—synthesizing specific empirical observations into broader patterns and meanings—and deductive reasoning, where these patterns were examined against established theoretical frameworks (Flanagan et al., 2024). The hermeneutic perspective informed the dynamic interaction between these two processes, ensuring that interpretations were both grounded in the data and connected to existing knowledge (Figure 1).

2.1 Setting and participants

Families were recruited from two major hospitals in Region Stockholm (Hospital 1 and Hospital 2). Recruitment took place in conjunction with the RCT in which a total of 38 families were recruited (Partanen et al., 2022, see Section 1). Inclusion criteria were as follows: preterm infants born at Gestational Week (GW) 32 or earlier, clinically stable infants with parents fluent in either Swedish or English. Infants could be recruited at the earliest when the infant was 28 GW. After some lapses, 28 families remained available for interviewing. Of these, $n = 20$ were from the intervention group and $n = 8$ from the control group. As part of the recruitment, all families, in both groups, filled in a form concerning duration of skin-to-skin contact and singing (Kostilainen et al., 2023; Partanen et al., 2022). Among the interviewed families, 27 mothers (M) and 18 fathers (F) participated in the study. There were no same-sex relationships among the families. There was one single mother, and one single father. The interviews took place when the infant reached the age of 5 months corrected age. The decision to interview the parents several months after leaving the NICU/hospital and completing the intervention was made to assess whether the CMT intervention had any enduring effect on parents singing to their infant at home after discharge. This has also been studied in the interdisciplinary “Transition to home” study in Switzerland (Haemmerli et al., 2021; Schütz Hämmerli et al., 2022) and in an international longitudinal multicenter study (Gaden et al., 2022). In a recent integrative review the authors suggest that music therapy could play an important role also after discharge (Clemencic-Jones et al., 2024). In our study, interviews were conducted with parents from both the intervention and control groups.

In the Swedish cohort of the Singing Kangaroo RCT study, families in the intervention group met a CMT-trained music

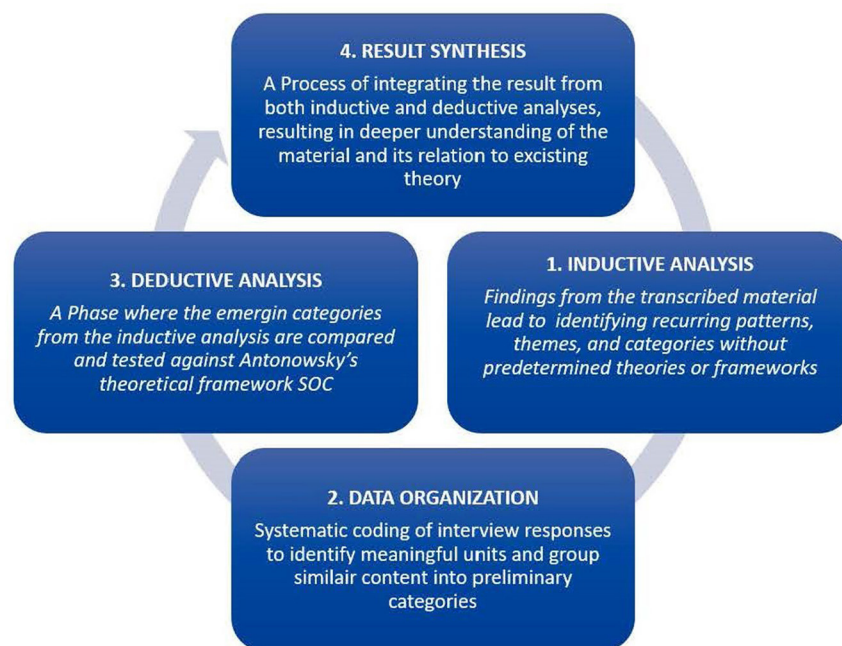


FIGURE 1

Outline of the data analysis process: beginning with inductive analysis to identify themes, transitioning to deductive analysis to test findings against a theoretical framework (e.g., SOC), and concluding with the synthesis of results.

therapist (author PH) twice a week during 4 weeks of hospital stay. Each music therapy session lasted ~45 min and was provided during kangaroo care. The music therapy sessions were conducted in an individualized and interactive way where parents were gently supported and inspired to use their voice in humming, singing, and vocalizing with their preterm infant. The music therapist had an undemanding and relational psychotherapeutic approach when reaching out to the families and aimed to guide the parents gently to find their own unique voice in an undemanding approach. The music therapy method used was in accordance with the CMT method (Haslbeck and Bassler, 2020). The parents' preferred way to sing to their infant was in an infant-directed lullaby style: a tender and warm voice timbre, a slow tempo, humming a repetitive melody without words in accordance with their infants breathing and movements. The music therapy sessions were tailored to both parents' and their infants' needs in the moment. They could consist of singing songs together, humming and vocalizing together, sometimes accompanied by the monochord instrument. These were moments of peace and quiet when listening to the music therapist's singing or humming improvising in a relaxed lullaby style or listening to the soft sound of the monochord. What was happening in the moment was thus emphasized and illuminated. This created space for dialogue addressing parents' needs to share feelings and thoughts (Haslbeck and Hugoson, 2017).

2.2 Data collection

The semi-structured interviews, conducted by author PH responsible for the CMT at NICU occurred between May 2015 and November 2018, were audio recorded using an Olympus digital

voice recorder VN-713PC. To ensure a comfortable environment, the sessions were conducted in the family's home. Interviews, held separately with mothers, fathers, or both parents together depending on the situation, often included the presence of infants. In two cases, fathers responded to questions via email due to personal constraints. To explore the parents' experiences, an interview guide with open questions and possible follow-up inquiries was co-designed (LE + PH) (see Appendix 1). The interviews were conducted in Swedish and took between 20 and 45 min each. After each interview the first author made field notes of personal impressions to remember better the context of the whole interview situation when listening, transcribing and analyzing the interviews.

2.3 Analysis

Interviews with parents ($n = 17$) from Hospital 1 were transcribed by the first author (PH) in an ongoing process during the data collection period. Transcriptions ($n = 11$) from Hospital 2 were made by a professional transcriber due to time limitations in January 2023. The interviews with the parents were transcribed verbatim, every pause and non-verbal utterance, such as laughs, sighs and humming were noted. The transcribed interviews were analyzed according to the method of Elo and Kyngäs (2008) using a manifest inductive qualitative content analysis. The data resulting from these interviews were then subjected to manifest qualitative content analysis using a deductive approach. The analysis began with several readings of the transcribed text to search for meaning and a deeper understanding of the entire data set. The first author (PH) and the third author (LE) read

the transcripts separately because important insights can emerge from the different ways that people consider the same data (Sandelowski, 1998). The authors initially shared their impressions of the interviews and collaboratively identified meaning units aligned with the study's aim.

After reviewing the material from the transcriptions of the first hospital cohort, a decision was made to apply a deductive approach, explicitly using Antonovsky's Sense of Coherence (SOC) theory, for labeling the categories (Antonovsky, 1979). Meaning units were differentiated using colors and then transformed into condensed meaning units, codes, and finally, three subcategories and one main category, organized in an Excel document (see Tables 1, 2). PH initially did the categorization matrix translation (Tables 1, 2) and later refined it through a peer review process involving all authors. As two researchers (LE and PH) participated in the coding, and one of them (PH) held dual roles as a music therapist and researcher, they independently tested the coding before extensive discussions between the authors on the categories. Any disagreements were resolved through discussions until a consensus was reached. To enhance credibility and trustworthiness, the authors provided a comprehensive description of the content analysis process and presented results from the original data, enabling readers to draw their conclusions following the method proposed by Elo et al. (2014). Data analysis continued until a certain material saturation was reached when no new information was found in the material.

2.4 Ethical considerations

The Swedish component of the Singing Kangaroo studies, encompassing the present study, obtained ethical approval from the Swedish Ethical Review Authority (registry number 2014/1318-31; supplementary approval for interviews, registry number 2015/0120-32, supplementary approval registry number 2016/2362-32). All participating parents provided written informed consent before participating in the study and prior to taking part in interviews. They were informed that participation was voluntary, and they had the right to withdraw at any time without providing a reason, and it would not impact future care for themselves or their infants. We randomized each family to a three-digit number code to ensure anonymization. Parents (mother = M, father = F) with the same number belong to the same family. The code list is kept in a locked cabinet to which only the research group has access.

2.5 Limitations and strengths

A limitation of this study is the potential for participation bias, as families with a pre-existing interest in music may have been more likely to participate, raising concerns about the representativeness of the clinical sample. Additionally, the unequal sizes of the intervention and control groups—a common challenge in qualitative research, as noted by Patton (2015)—may have affected the depth and breadth of the findings. Smaller control groups can impact the balance of data and require careful interpretation to ensure credible conclusions. Nonetheless, the dual-group approach enabled meaningful comparisons, highlighting both shared and

unique parental experiences between the CMT and standard care groups. Another limitation was that the same researcher (author PH) conducted both the clinical intervention and subsequent interviews. While this dual role provided valuable contextual insights, it may also have influenced participants' responses. Patton (2015) underscores the importance of transparency in addressing such design decisions to maintain methodological rigor. To mitigate potential bias, both authors (PH and LE) independently analyzed the interview data during the initial phase, which strengthened the credibility of the findings.

This study employed a robust two-stage analytical approach, combining inductive analysis to identify patterns with deductive analysis grounded in the SOC framework (Antonovsky, 1979). As the first qualitative inquiry in music therapy within neonatal care, it provides valuable insights into parental experiences in both intervention and control groups. However, the significantly unequal group sizes limit generalizability, as variability in responses was constrained in the smaller control group, potentially influencing the findings. Future research should address these limitations to enhance comparability and rigor.

3 Result

The results emerging from the inductive process revealed the themes of *feelings of safety, closeness, empowerment in parenting and healing*. The deductive analysis that followed, using the theory of SOC, resulted in three subcategories: *manageability, comprehensibility, meaningfulness*—the main categories of the concept *Sense of Coherence* (Figure 2). The subcategories coalesced into one main category: *Sense of Coherence* (see Tables 1, 2). A sense of coherence is achieved when manageability, comprehensibility, and meaningfulness are in harmony with each other. Each subcategory is illustrated with quotations to illuminate the categories with the parents' own words. To distinguish between the CMT-intervention group and the control group, the results are presented under separate subcategory headings.

The Venn diagram (Figure 2) illustrates the possible intersections between the three concepts of *Comprehension, Manageability, and Meaningfulness*. The overlapping regions between each circle visually depict shared similarities between the concepts. However, SOC occurs only within the region where all the circles intersect. The Venn diagram derives all the concepts "floating around" from the parents' interview responses.

3.1 Manageability

3.1.1 Intervention group

The majority expressed difficulties in managing their situation in the NICU. Becoming a parent to a fragile and ill infant is not an easy task. They reported that singing with their infant helped them to be more present and find relaxation in those moments.

348M: I found it very comforting, quite liberating actually, to sink into, like, a song for a while, it was very relaxing! Both for me and for her [baby] It was incredibly stressful when we were in

TABLE 1 Examples of content analysis, intervention group.

Meaning unit	Condensed meaning unit	Code	Subcategory	Category
I was able to calm myself down. If I was sad, which I feel I was quite often, or angry at someone, I thought that I felt better by singing. It felt... well, everything became more positive.	Singing made me feel better and I calmed myself down when things were difficult.	Comfort Wellbeing	Manageability	Sense of coherence
I feel that she becomes calm, that she enjoys hearing my voice. I think it's the response from her that makes me continue.	She becomes calm, she enjoys it. The response from my child provides motivation.	Wellbeing Communication Motivation	Comprehensibility	Sense of coherence
Then you came and you sang for us and with me and it went really well! [...] I have been inspired by you and I sing much more for her since I met you. [...] We also got a lot of emotional support!	It was supportive and inspirational to sing together with the music therapist and the emotional support was valuable.	Emotional support Inspiration	Meaningfulness	

TABLE 2 Examples of content analysis, control group.

Meaning unit	Condensed meaning unit	Code	Subcategory	Category
I didn't think it was so noticeable, but others said that they thought she reigned in and became calmer, but I don't know... it felt like I was doing it more for me!	The singing became something that I did to calm myself because I couldn't see that my baby reacted.	Relaxing	Manageability	Sense of coherence
The reason why you sing is perhaps to make the child feel safe and calm and so on and to recognize your voice.	I want my child to be safe and calm so I sing.	Reassurance	Comprehensibility	Sense of coherence
You get closer to each other when you do something together [...] it made us think about something else, and I think we got closer to them [...] it became a break from other things [...] so it's also a good way to take a breath.	A closeness when singing together, a break and a way to breathe.	Togetherness Wellbeing	Meaningfulness	Sense of coherence

the emergency room... [...] At that moment, it was good to be able to relax for a while.

551M: But it's a way to communicate with him [baby], I'm calm and I want him to be calm while we're together here.

Several mentioned feeling anxious about their infant and experiencing a sense of losing control, unable to care for their infant as they would like. For them, singing became a strategy for managing their situation.

909M: The song itself, for me, was initially a way to disconnect from all the chaos [...]. It allowed me to focus on singing and being in the moment. Looking back, it was like small oases in a little chaos. Physically, I felt that I could relax in those moments when X. was upset and there was something going on, and then we sang!

236M: I remember it as cozy to sing in the emergency room. It was like creating a private space [...] Singing becomes like a mantra for yourself... I think I mostly hummed, actually... a way for him to hear my voice! Even if I didn't have the ability to talk to him, which might have been because everything was challenging.

Additionally, some parents shared that singing helped them manage the stress experienced in the NICU, serving as a tool for comforting both themselves and, by extension, also their infant.

551F: Then I notice that it's [parental singing] a tool too, once you start using it... it's practical; you can calm him down, you can see that. Especially in the neonatal unit [...] I found

it easier to calm him down with a little song. [...] you yourself [parent] become calm with the music, with your calmness, he becomes calmer too.

A significant number of parents also noticed that singing was a way they could help their infants calm down during skin-to-skin contact, making them more content. This calming effect was evident, often causing infants to fall asleep instead of being restless.

969+983M: They [babies] could be a bit restless when we had skin-to-skin contact – it was mainly at that moment we used to start singing. They often fell asleep instead of fidgeting around, especially the girl, I think, because she didn't really want to lie still. She was probably bothered by all the equipment and such, so I think it helped to calm her down.

551M: I think it was a way for him [baby] to find tranquility amidst all the beeping and all the tubes and machines and everything... because he usually fell asleep... it was a cozy moment... which I believe he enjoyed too.

Singing served as a meaningful and constructive activity for many parents, particularly those with infants enduring an extended hospitalization. It was described as a valuable way for parents to manage themselves positively during the challenging time at the NICU. Singing provided a helpful distraction, allowing several parents to focus on something other than the hospital environment and the challenges their infant was facing.

969+983F: It was a way to occupy oneself! [...] Especially for those who are hospitalized for a long time, it's very good that you get something else to do, you get a way that can help your children, it helps parents to think about something else.

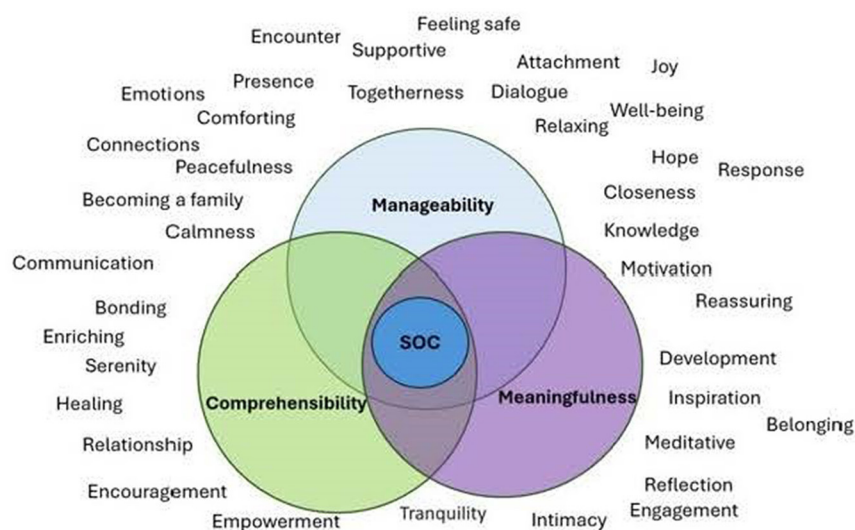


FIGURE 2

Venn diagram showing the possible interscctions between the three sets comprehensibility, manageability, and meaningfulness.

132M: It felt good to be able to do something for your child. [...] we really felt that it was very important for us to sit a lot skin-to-skin and then that you could add one more thing, to sing and it was good!

Certain parents mentioned struggling to feel fully present with their infant, as they also had to care for siblings at home. In this stressful situation, they found the music therapy sessions to be relaxing—a peaceful pause from all their duties.

508M: Yes, it was calming and distracting from all the other thoughts I had about organizing how we would handle things with my older son and how I would get to see him. Since you automatically smile when you sing, you feel more positive.

111F: I think that in that situation you get really stressed. I don't think there is any other situation where you get so stressed: a child that was born prematurely and also like we had our second daughter. I think the best thing is to sing, it helps calm both you and the baby!

Commencing singing in the NICU presented challenges for several parents, with feelings of embarrassment and initial discomfort commonly acknowledged. It also required a period of time for them to comprehend the benefits for their infant. Once this realization transpired, the task became more manageable and facilitated a stronger connection with their infant.

930M: It was a bit scary, and it probably has to do with the fact that I haven't sung much [...] but it still felt good because it felt like it gave her something.

862F: In the beginning, it was a bit tough, but then it got better [...] it was a bit embarrassing at first, but it eased up after a while.

3.1.2 Control group

Most parents in the control group who sang to their infants found singing to help create a sense of manageability. Additionally, singing in the NICU became a playful and engaging coping mechanism in the challenging environment. Humming, particularly at night, served as a means to deal with hospital noise and fatigue.

123+724F: It became the most playful in the NICU [...] this singing activity was something different that we could engage in.

338M: I hummed a lot at night in the hospital, there wasn't much you could do about this grunting and when there was a lot of noise, and noise like that, I stayed in bed and hummed because I was so tired, so I hummed instead.

Certain parents in the control group contemplated that participating in a singing group, where they could gather inspiration and mutual support from other parents, would have constituted a favorable aspect during their hospital stay.

338M: [...] there could be a group where you could get positive input on what you can do and music could be part of that...and get the opportunity to meet the other parents also on a more positive basis.

776M: You might be able to come to the parent lounge much like at an open preschool, so the parents and children who can join can be there and only hear music, that would be nice!

One mother additionally expressed that it would have been beneficial if healthcare personnel had taken an active role in the singing process or provided guidance to parents on how to utilize singing as a coping mechanism in the NICU setting.

776M: Maybe the rest of the staff also have to encourage and support parents to come and that it works with the other care.

To sum up manageability, the first key concept of SOC, the results from the intervention group indicate that parental singing served as a valuable strategy to calm the infant, particularly in the NICU. Parents highlighted its usefulness in soothing the baby and bringing a sense of calmness to themselves, especially in high-stress situations in the NICU. Singing was viewed as a practical and effective tool to manage stress, fostering a calming atmosphere for both them and the infant. In summary, singing served as a tool to manage tranquility and comfort, creating a positive and enjoyable experience for both infants and parents in the challenging NICU environment. It was perceived as a proactive way for parents to manage both their infant's wellbeing and their own wellbeing, adding a positive element to their hospital stay. Interestingly, only the parents of the control group expressed that they would have needed more support in singing.

3.2 Comprehensibility

3.2.1 Intervention group

Comprehensibility is linked to knowledge and the capacity to contemplate emotions and thoughts, enabling parents to recognize their new parental role. As parents in the intervention group progressively became more acquainted with their infant and grew more at ease with singing, the situation became more comprehensible. This, in turn, facilitated a better understanding and acceptance of their situation.

909M: I think that before we met you [music therapist], it felt like... I probably didn't think of X as a child [...] So for me, it was like, "Oh, you can also sing for such a small child." Then he became a bit more human, and I've probably felt it even more during the autumn as he has grown, that now it feels even more natural to sing.

930F: It felt good to do it [singing], it felt intimate, and like it maybe made one's presence more tangible for the child. I think it was good both for establishing a stronger connection and for getting the child accustomed to oneself while providing more comfort by marking one's presence.

Music therapy sessions proved to be enlightening for some parents, providing insight into their infant's distinct communication abilities. The music therapist elucidated the infant's ability to express itself and interact. Together with the parents, the music therapist reflected on how their infant interacted in the moment. This heightened comprehensibility contributed to parents' understanding and coping mechanisms during the hospital stay, as they observed their infant actively engaging with music. Notably, without the therapist interacting with the infant, some parents may not have spontaneously considered singing as a means of interaction.

826M: But then, I thought above all that what was cool was when you [music therapist] came, and I could see that she responded... I didn't think she was responding to me, but

then, when I began to be able to see it, it became almost even more important. Like, "oh, she understands this"... and choosing songs with care and all, that I want this [...] I thought it was cool, especially when I noticed that she understood more than I thought about what it meant.

909M: At the hospital, you [music therapist] demonstrated the signs he [baby] displayed in response to the song, and when you showed that, I understood that he was taking it in as well. But I probably wouldn't have spontaneously thought of singing.

Numerous parents experienced a sense of wellbeing in their infants during singing and music therapy sessions. They described how their infants seemed to recognize their voices and presence, exhibiting relaxation when they engaged in singing. These encounters enhanced the comprehensibility for parents, affirming the significance of their singing in positively influencing their infants.

969+983F: It was when we [parents] achieved that vibration in the chest bone that they really relaxed after a while.

134+505F: I experienced that the children felt secure and recognized the songs I sang.

930M: I think she became a bit calmer [...] this closeness made her more engaged, a shared experience maybe in some way.

Some parents perceived singing as an intuitive way to communicate with the infant. They emphasized that when they sang, the infant heard and responded, establishing a connection similar to talking. Singing was seen as a natural and effective means of communication, allowing the parent to connect with the infant and observe their engagement through looking and listening.

742+115F: When you sing, they [babies] hear a lot, you often get in touch like that when you sing. You don't sing into the air, you sing to them. In the same way as when talking.

551M: I find it natural that one wants to sing; I think it becomes another way to communicate. You establish a connection with him [baby] and see that he's looking and listening.

Several parents felt that their voices and presence meant something to their infant, something unique that no one else could provide for their infant that created a special bond between them and promoted their relationship. In this way their singing to their infant became highly comprehensible in their process of becoming parents.

551F: Just to create a bond, it will be something personal and it will be something he [baby] will recognize... he knows my voice, and knows what I'm singing... that's what you're creating here, a relationship [...] There must be a difference between us and others. We are his parents.

In interviews, numerous parents expressed that their engagements with the music therapist yielded new insights and a fortifying experience. They acquired a heightened comprehensibility regarding the positive effects of singing, acknowledging a substantial shift in

perception and recognizing it as genuinely beneficial for their child.

111M: *Yes! God yes, yes! I had some idea before and a feeling but then, when we met and I've been doing this research and this so...and so this book that you [music therapist] gave me. It has changed me completely, much more! So it's something that's really, really is good! Before I had a faint idea, but it was something I couldn't really put into words... but it felt good, that's how I felt! So it has definitely changed!*

A handful of parents not only shared their infants' experiences but also discussed their own emotions while singing and during music therapy sessions. Certain parents described this as a healing experience and a catharsis, the process of releasing strong or repressed emotions, thereby providing relief.

477M: *I remember the second time we met, you [music therapist] sang "Trollmor" [...] I just cried so much... Then, I recalled the entire childbirth [...] Yes, it was like catharsis, like cleansing... I always become emotional with "Trollmor" [...] When I think of that song, when I hear that song, it reminds me of the childbirth or the moment when you sang for us [...] I just opened my heart and looked at what lies there.*

348M: *I felt it, especially when we sang there in the emergency room... yeah, there were a lot of emotions that came out when we sang! Especially with these slightly sad lullabies, it was very liberating... because that's how you [parent] felt at that moment, you were kind of in grief, so it was really nice to sing some sad lullabies. Yes, I actually liked it! [...] because there was maybe a lot that you [parent] couldn't put into words or say and so on... there were so many emotions that it was difficult to handle everything, I think, because it was like a storm inside!... then, to sing, it was kind of like relieving that pressure somewhere, actually!*

Numerous parents disclosed that intense emotions were evoked during music therapy sessions, whether through singing together during sessions, listening to the music therapist sing, or singing alone with their infants, contributing to a heightened sense of wellbeing. One parent spoke about the music therapy sessions as helpful in handling their grieving process.

111M: *I used to feel good after our meetings, I became calm! It provided positive energy, so I appreciated that too! I used to be in a bad mood or sad or something when you [music therapist] came, I remember, but then... I felt better and calmer when you left.*

551F: *It was quite emotional sometimes, it was. Especially with the loss of X. there... it was... you [parent] got some outlet for the grief, I think, through the music and that... it was a bit that it helped to move on from everything that happened. [...] when you [music therapist] were about to come with your music sessions and enter our room, then there were mixed feelings like "no, what's going to happen now, am I going to collapse there?" but then when it was over, it was nice. You [parent] often had a positive feeling afterward... there was always a positive feeling afterward. In the end.*

3.2.2 Control group

Also parents in the control group who sang felt that their singing had an impact on their infant in a positive way that made it comprehensible.

927M: *She [baby] became calmer and felt safer, and she recognized what I sang to her in the womb. It felt like she became happier. When you sing, the child feels happier, safer and calmer! It's the same with adults.*

For certain parents in the control group, maintaining a regular singing routine for their infant in the NICU posed challenges, particularly in the early stages when the infant was fragile. Singing became more ingrained as the child reached 3–4 months of age and the stress associated with the hospitalization lessened. Parents sang both to soothe the child and, in retrospect, for their own comfort. Singing facilitated a sense of connection, involving physical touch and humming. However, initially, parents grappled with singing certain songs due to intense emotions, including worry, sadness, and fear.

034M: *Yes [I sang] a few times but it was nothing regular... I also think it has to do with the fact that he [baby] felt so fragile in the beginning... it didn't feel natural to sing to him. [...] it was rather when he was three to four months old, that was probably when I started singing. [...] when all that had to do with the hospital disappeared, it was probably then that I could feel that I was here with my child.*

338M: *It was actually meant to calm her [baby] down, but I think in retrospect it was mostly for myself. Because what you could do was to hold hands or something and sing and hum. [...] I sang almost right from the start, but then I mostly did it when there was no one else around at first. I thought it was very difficult. I almost couldn't hum something like "Vem kan segla" without starting to cry, there were several songs that I couldn't sing without my voice starting to tremble, I had to choose songs that I could sing... it was a lot that happened then! Much worry and sadness and fear and such!*

The initial hesitancy and challenges experienced by some control parents in singing to their infants evolved over time. As certain parents persisted in this practice, they began to notice positive changes, with infants displaying increased calmness and improved ease in falling asleep. These observations suggest a growing comprehension of the soothing impact of singing on the infants.

123+724F: *Initially, it felt more challenging... I didn't know if they [babies] noticed anything [...] I eventually started noticing that they might become calmer at times and also fell asleep more easily.*

The hospital environment, characterized by decisions made by others, led certain parents to perceive a lack of authenticity in their parental role. Singing emerged as a distinctive and personal avenue for them to participate in the care, representing a significant opportunity to contribute actively to their child's wellbeing. This engagement with singing brought a positive and empowering dimension to their parental role, enhancing

their sense of comprehensibility and contribution in the caregiving process.

776M: *What I can also feel, when you were in hospital, you [parent] don't really get a chance to be a parent, someone else decides everything you have to do, but singing is something that only I can do and give this care instead of nurturing with medicines or with equipment in this way. You feel pretty bad as a parent in such a way that you don't know how to take care of your child. So it was nice when you could take care of your child in that way.*

To sum up, data collected from the intervention group indicate that singing, especially slightly sad lullabies like “Trollmor,” became a means of expressing difficult emotions, providing relief, and releasing internal pressure during a turbulent period. In this way, parental singing contributed to the comprehensibility of emotions related to childbirth and challenging moments, often associated with traumatic experiences. In contrast, the parents of the control group did not express the singing as catharsis and letting feelings go; instead, certain control parents expressed that when the singing evoked strong feelings, they hesitated to sing those songs to avoid eliciting such strong feelings. The results from the intervention group indicate that the parent's perception of their infant changed after meeting the music therapist. Initially, they did not fully perceive the infant as a responsive baby beyond basic needs. Singing played a transformative role, making the infant appear more human, establishing a stronger connection, and creating intimacy. Over time, as the infant grew, singing became a natural and meaningful way for the parent to assert their presence, strengthen the connection, and offer comfort, for both intervention and control groups.

3.3 Meaningfulness

3.3.1 Intervention group

Many parents found singing for their infant a meaningful, comforting, and bonding experience, awakening deeper emotional connections. Despite the infant's minimal reaction, it created a connection and enhanced togetherness. Described as therapeutic, calming, and special, these moments' significance became more apparent in retrospect, emphasizing the depth of the bonding situation.

020+509F: *...it's very cozy to just sit there... that communication we [parents] got somehow, even if they [babies] didn't react a lot when we sang. They hear you [...] that thing about forming a connection, so they can recognize your voice.*

826M: *When she [baby] lay in the incubator and we sang, it was probably half or 75 percent therapy for me, just singing “Byssan lull” like some kind of mantra [...] I felt that I became calm from it. [...] it also served an important function for me, [...] these moments became very special... we sat there in that chair and sang and sang. [...] It becomes some kind of bonding situation in some way that I probably didn't understand then, but that I can see now.*

Numerous parents reported that when they sang, their infant became physically close, creating a sense of emotional closeness. They described this experience as deeply meaningful.

930M: *...it was still like this... happiness to have this contact, it was more intense, it felt like she [baby] became more present, not just that she was close [...] singing made it even closer.*

808F: *It was cozier to be just me and X, we got a different connection somehow [...] I felt it was very intimate.*

One parent also described the music therapy sessions as very relaxing moments and underlined particularly the harmonizing, uniting and blending effect of the monochord for them and how it strengthened their process of becoming a family.

748M: *Yes, I thought the monochord was really cozy... it was very harmonious. It felt like we ended up in our own family bubble, that we became a unit, suddenly becoming a family.*

The CMT was acknowledged as emotionally supportive and empowering in the transition to parenthood. It offered comfort and tranquility, providing reassurance through the music therapist's guidance and dedicated time. Additionally, the CMT sessions contributed to the overall journey of parenthood, aiding in navigating challenges in the NICU and fostering a meaningful connection with the child.

930M: *It was a comfort... it became like a calm. And then getting some tips on how I can use my voice and a little more to make it easier for both of us, that was reassuring. It was very nice because someone [music therapist] came and really took the time. [...] And it gave a lot for oneself too, I think I became a bit strengthened, I didn't need to worry so much [...] After each session, you [parent] felt that personally, you took another step... dared to believe in yourself a bit more in the new role as a mom. [...] It has given so much... on the whole journey and to the person I has become as a mom today.*

551M: *After all, we had to learn to be parents in the NICU. But it was difficult to get into that role because of all this stuff around. And then the song and this became a way to get close to your child, to get to know him, I think.*

The CMT sessions were described as recurring and anticipated moments, providing a broader meaning and context to the otherwise routine-driven existence at the ward. Certain parents described how music therapy sessions made their days in the hospital more meaningful.

909M: *Then it [music therapy] became something to look forward to and to hang on to the thought of, getting to meet you [music therapist]. To go from my life before to sitting in that family room, it still became a different rhythm and to meet another person [music therapist] and to talk about something else that wasn't directly about pumping milk.*

826M: *That it [music therapy] was also something that made the days go by and think about something other than ultrasounds and hearts and all that... but now we're going to have some music too.*

The connection between parents and music therapist during music therapy was regarded as meaningful by some parents. They highlighted the therapeutic nature of their interactions with the music therapist, emphasizing the value of dialogue to reflect on and organize their thoughts and feelings, thus contributing to the overall sense of meaningfulness in their relationship with their child. One mother especially emphasized it as important that the music therapist was not someone who was responsible for her infant's daily care and because of that the dialogue became more open and supportive in another way.

057F: *I think you [music therapist] are very good; we have had very good conversations on all sorts of topics. So, the whole thing that in an unforced way you [parent] have the opportunity to reflect, feel, put into words how you think and feel, I think that's actually great!*

909M: *And all that support I got from having a conversation with you [music therapist]! Who is not a healthcare professional, who does not look after X. in that way, but who has a different angle and something that we [parents] could choose ourselves and that I became very interested in.*

Music therapy and singing served as an emotional space where some parents could find respite from worries and other negative emotions and also respite from challenging and difficult thoughts about their situation. This emotional engagement was seen as contributing to the meaningfulness of their experience during the intervention.

748F: *... very calming, especially this one with the monochord [...] it was a chance to escape from reality and I thought that was very nice. [...] I think you [parent] need it and it was also a nice break in everyday life, which is otherwise very routine driven in the NICU. So then you [parent] had something else to think about or talk about.*

057F: *I thought it was cozy when you [music therapist] were there. It was nice, that little harp you had, it probably provides a calmness that is pleasant to be in. I appreciate it; it's somehow meditative, so I think it's great. It's the presence, it's something special about live music.*

Certain parents highlighted experiences of loneliness during their NICU stay. They emphasized that the dialogue and the chance to be present in the moment, free from demands, during CMT sessions, were profoundly supportive and meaningful for them. This finding underscores the role of CMT in addressing emotional challenges and fostering a meaningful connection for parents in the NICU.

348M: *I thought it was great, really great! Partly it was nice to sing and get inspiration for it, but then I got so much support in our conversations! It was so incredible; it really meant a lot because... I was also quite lonely there in the ward...so it was great when you [music therapist] came and we actually got to talk a bit. So that it wasn't just the song, but also that you [parent] got a moment to sit and reflect on everything and talk a little, you actually needed that.*

It seemed that music therapy, the contact with the music therapist and starting to sing to their infant gave several parents a context that made their stay in the NICU more meaningful. Music therapy in the NICU was not something that they had expected but that became very important to them during hospitalization with their infant. They described the calming effect and the closeness as highly meaningful.

348M: *It's not something you [parent] might come up with yourself, that it's SO good to sit down and sing with your child. [...] so as to get inspiration to sit down and sing for a while. I thought it was really, really nice!...and just that you [parent] took that moment with your child, it actually became such a small quality moment. [...] because it wasn't just the music, but the fact that you sit down close to your child and you get in touch and you notice that the child relaxes and maybe falls asleep, so it's really nice!*

969+983M: *I think it's good too, I would not have expected that in the NICU... I really believe that the calming effect it has on both parents and children is very important in the situation you [parent] find yourself in!*

After discharge from the NICU all parents reported that they continued singing to their infant at home. Singing had seamlessly become an integrated part of their family life, and they expressed profound appreciation for the meaningfulness of this practice. This finding suggests that the practice of singing persisted as a meaningful and valued aspect of their family routine post-discharge.

111F: *...now she [baby] grows up with singing all the time...and our voices and with the same song and that, it calms down at once. She becomes happier.*

974M: *Now I think it [singing] comes so spontaneously, now it comes all the time. I don't think you think about it, but you sing quite a lot [to father]. Me too! I sing her name and when changing diapers. I think you [to father] sing to her more than you talk to her.*

508M: *He [baby] reacts, he smiles and laughs, he moves. [...] I respond to his sounds, imitate him and sing to his sounds or make up songs based on what he says.*

969+983M: *I sang a lot for her [baby] last week when she was going to have surgery. I sang when they were taking a blood sample and when she needed to be still for an examination. It was clear that she calmed down when I sat there and sang. But I also sing sometimes and play around with them [babies], and then they smile and laugh occasionally.*

One parent told about that the continued singing at home awakened memories of songs from her own childhood and it became meaningful to share them with her infant.

551M: *And then other songs come up that you yourself [parent] have learned when you were little, that you sing...you are drawn back to your childhood. So I think it's wonderful and very nice to be able to sing my favorite songs.*

A number of parents characterized singing at home as a means to support and nurture the evolving relationship with their child, highlighting its role in strengthening their parental identity. This finding underscores the meaningfulness of singing beyond the hospital setting, positioning it as a purposeful and identity-affirming practice for parents.

808M: *To give security...belonging... it becomes a cozy moment, and you connect with each other and it becomes intimate. [...] this [singing] is something that you will really continue with, I feel, it is a very natural part [...] yes I think that it furthers our relationship.*

551F: *You have your songs [to mother] and I have my songs...you [parent] get a different connection, your personal connection to X through what you sing. [...] Yes, but somewhere it [singing] has become his...a part of him thanks to this thing we've been doing, the singing. It becomes a bit like a part of him. So, you [parent] like to keep doing it, you don't want to skip it.*

In discussing singing at home, several parents emphasized the multitude of emotions it evoked, both for their infants and themselves. These findings underscore the meaningfulness of singing in the home environment, illustrating its capacity to elicit a rich emotional experience for both parents and their infants.

236F: *Yes, I become happier myself! It's somehow enriching to spend time with X in several different ways. [...] it's happened that I've had the feeling that he sings along, tries to sing along and also there are certain songs that he can laugh at and stuff like that.*

930M: *She [baby] becomes happy, I become very happy. [...] now you get a completely different connection and then there becomes a completely different closeness [...] we also talk a lot during the day, but the singing in particular is a little more...yes...a little more joy...that is, feelings.*

Furthermore, the practice of singing at home evolved into a shared activity for some parents, adding a layer of meaningfulness and enjoyment for both parties. This finding highlights the collaborative and enjoyable nature of singing within the home environment.

020+509M: *It's also so fun that it [singing] has become something that me and X [dad] do together[...] it's positive for us to sing as well, it's fun to sing.*

The majority of parents regarded music therapy, especially singing, as an integral supplement to the medical care received in the NICU. In hindsight, they viewed singing as a meaningful addition to the routine care provided in neonatal wards, acknowledging its potential to offer parents a break from the customary tasks of caregiving and medical assessments. This finding underscores the perceived significance and positive contribution of singing to the overall neonatal care experience.

930F: *I definitely think it [music therapy] can be a good adjunct to "usual care". I also think that it can be a welcome feature for the parents as it can be a break from the usual routines of care and medical checks.*

134+505F: *I thought the contact with you [the music therapist] was good. We probably wouldn't have thought about the meaning of singing without this contact, so it was appreciated. Then we could also talk about other things too, which was good. I absolutely think that this [music therapy] is a good feature of the medical care in neonatal-wards.*

A handful of parents regarded singing in neonatal care as an essential component of the healing process, wanting it to be available to all families to support parenting and foster coherence. They perceived singing as a valuable tool for establishing a close connection between parents and their infant, providing a unique and positive means of interaction. Stressing the importance of comprehending and promoting the significance of singing in a pedagogical manner, parents believed it could enhance therapeutic benefits for both parents and infants. This finding highlights the meaningful role parents attribute to singing in the context of neonatal care, emphasizing its potential positive impact on the parent-child relationship and the overall wellbeing of families.

862M: *I think this [singing] is a very important form of a part of the healing process that is very important! [...] So, I hope this [music therapy] gets into neonatal care and like really, really all babies even full term would need it. Because I think singing can be a tool to get close to your child! [...] And that's why I think, or I wish, that you could work more with singing as a healing method... Yes, as a tool for parenting... it is. You can hum and be tone deaf but still it's nice because you have a moment with your child...so...I think it's something you should have more of!*

862F: *[...] it is, and if you can encourage and help to encourage others in a pedagogical way so that you understand how important it [singing] can be and how good it can be...and help on the trot, so to speak, with that bit, I think it's good! Really!*

3.3.2 Control group

Certain parents in the control group who sang described it as meaningful and important in their journey of parenthood.

776M: *I felt like a good parent. I think it's something that, as a parent, I have to sing for my children and when you do it, it just feels good, you feel good and it's very cozy!*

Several control group parents, upon returning home from the hospital, initiated singing with their infants, with some adopting this practice from the outset. Upon reflecting on their motivations, these parents highlighted the significance of shared emotions, viewing singing as a communicative tool and acknowledging its importance for the child's development. This discovery underscores the meaningfulness that parents attribute to singing, emphasizing

its role not only as a form of communication but also as a deliberate and purposeful activity intended to nurture a connection with their infants and support their developmental journey.

524M: *It [singing] is like a language and a communication between us. [...] Yes we are on the same emotional level, we share feelings through it. When I see that he [baby] is sad, I hug him and sing a sad song... when we are happy, we sing something happy. [...] I think it affects in different ways, his well-being too... he feels safer and it's also a fun thing we do together.*

034M: *That it's fun, I notice that he [baby] gets excited when I sing... he thinks it's great fun. [...] I think that the more you stimulate your children with a song, talk or something, I think it's clear that you stimulate the brain, they [babies] get impressions, and they feel a sense of belonging... I think that's super positive!*

Control parents in the study gathered inspiration from various sources, such as their professions, literature, and interactions with healthcare professionals. This multifaceted approach to finding inspiration highlighted the meaningfulness parents associated with incorporating a variety of influences into their singing practices. Also, the weekly contact with the music therapist gathering the diaries and then talking about everyday challenges fostered a therapeutic relationship and for some control parents were also supportive to them beginning to sing.

927M: *Maybe from you! But I did it [singing] with my first child too, it's normal, I think. What you did with the first child, you also do with the second. [...] I am also a nanny and have knowledge from my profession. I do it in my job all the time and with big brother. And now I do it all the time singing to her. Then I've read a lot of books about how the child reacts and how the child becomes if you sing and if you talk to them and how they develop and so on. It is natural.*

338M: *Because it felt like it [singing] was the only thing I could do for her [baby]. I hardly dared to touch her... and it was hard to touch her, there was so much stuff and it felt like I couldn't do anything, so I took the ones [songs] I could, there was a lot of humming rather than singing. But then I contacted a colleague who holds Baby Rhyme sessions and asked for some songs. [...] At H [other hospital] I thought they were encouraging and a doctor there was humming to herself when she removed the tape to calm down and it was a bit inspiring and then it felt like then I can also do this if even she [the doctor] does it! [...] they [nursing staff] encouraged us to talk or sing... and since we couldn't do much, they thought it was important for us to sit there and talk or sing. I found it difficult to sit and talk so I preferred humming.*

The collective engagement in singing proved to be a meaningful activity for one control group family, fostering a shared experience between both parents.

123+724M: *But it was still very nice that we're doing something [singing] together, that I'm doing something for the children, it felt very cozy. [...] We sat in our own armchairs, each with a child on our stomachs, and sang together.*

Several parents in the control group acknowledged the value of seeking guidance and support from a music therapist or engaging in music therapy during their NICU stay, emphasizing the meaningfulness of these interactions.

034M: *I think it's great, for some music is not natural at all, to sing to your child [...] I think it's good both to get those who already have it in them started but maybe also to inspire those who music doesn't come naturally at all. [...] I probably would have needed that nudge because I thought I ought to sing for him [baby].*

927M: *It's good that it [music therapy] exists! You [parent] get support so that you feel safer if you think it is difficult to sing. You might feel more secure and that you are doing something that is good and that even if you might be doing it yourself, it might be easier if someone else [music therapist] helps.*

Concerning the last key concept of SOC, meaningfulness, numerous parents from the CMT-intervention group expressed how music therapy during their time in the NICU gave them something to hold on to. CMT became a source of emotional-social support and strength in the journey of becoming a parent, offering valued personalized accompaniment, comfort, calm, reassurance, advice, and dedicated time. Moreover, CMT sessions played a meaningful role in the overall experience of parenthood, helping parents navigate challenges in the NICU and fostering a deep connection with their infant. These sessions served as a precious break from the stress of the NICU, contributing to a sense of meaningfulness and benefiting both parents and the infant. In the control group, parents also talked about singing as a meaningful way to connect with their infants. They talked about how other sources inspired them to sing and that the weekly dialogue with the music therapist collecting diaries was supportive. The control parents, when asked, also reflected upon which support they would have needed from the music therapist if provided.

Even though we didn't specifically ask about negative experiences, the results do not reflect any negative or critical quotes from the parents in either the intervention or control group.

4 Discussion

The aim was to investigate the potential impact of CMT in the NICU on enhancing the sense of coherence in parents as they sing to their preterm-born infants during kangaroo care. Additionally, we explored whether CMT had any significance on family life after the NICU stay. Our findings indicate a positive influence of CMT on intervention parents' experiences of singing to their preterm infant during kangaroo care and by increasing their sense of coherence in terms of manageability, comprehensibility, and meaningfulness. All parents in the intervention group experienced that CMT was a music therapy method that strengthened them as parents and was helpful in supporting the incipient relationship building with their infant when engaging in singing. The inductive analysis revealed recurring patterns within the dataset, identifying key thematic elements associated with positive emotions and

experiences. These identified themes encompassed *feelings of safety, closeness, empowerment in parenting, and healing*, merging into the overarching category and framework of the SOC so that after the first inductive stage of analysis, a deductive confirmatory stage was embarked upon in which we tested the categories found according to the existing framework of SOC.

Similar experiences of CMT have been documented elsewhere (Kehl et al., 2021; Haslbeck, 2014; Haslbeck et al., 2021). Kehl et al. (2021) reported relaxation for both infants and parents during singing as a key finding, along with parents associating relaxation with the intimacy it fostered between them and their infant. Our study corroborates these findings by demonstrating parental singing as a practical and effective tool to soothe the infant, especially in the NICU. The results indicate that singing may serve, not only to calm the baby but also the parents, as a valuable strategy for them to manage their stress and create a calming atmosphere for both them and the infant.

In discussing the importance of safety for relaxation and the subsequent creation of closeness as a foundation for interaction, it is essential to draw upon the insights provided by Porges (2011) and Sanders and Hall (2018). According to their research, when parents feel secure, they are better equipped to relax with their infant, fostering a sense of closeness through activities such as singing, engaging in small talk, and gentle caressing (interaction). This interaction initiates a cycle of co-regulation, where both parent and infant contribute to each other's relaxation, resulting in an immediate reduction of stress, and a broader sense of meaningfulness derived from the shared experience of closeness. In our study, participants often described experiencing what Stern (2004) terms "now-moments" during relaxed and intimate interactions, where parent and infant emotionally attuned to one another, thereby strengthening their relationship. These "neonatal moments of meeting" are foundational for bonding after birth (Bruschweiler-Stern, 2009) and represent meaningful therapeutic moments of change in CMT. Within these moments, parent and infant synchronize and attune through communicative musicality (Malloch and Trevarthen, 2009), aligning in pulse, timing, and vitality forms (Haslbeck, 2014). We interpret the SOC as reflecting the closeness and relationship between infant and parents, paralleling the synchronized interactions that foster these valuable "now-moments."

In our study, intervention parents describe such moments with words like closeness, presence, bonding, and intimacy when feeling emotionally and physically close to their infant. Similar findings were reported in Haslbeck et al. (2021), where parental quotes echoed these sentiments. Despite the passage of several years since their interviews, parents vividly recall how CMT helped them and their infants relax, fostering empowerment and strengthening the parent-infant bond.

Parents in the intervention group emphasized the importance of their relationship with the music therapist, particularly highlighting responsiveness as a crucial aspect of CMT. This aligns with the findings from a previous study (Haslbeck, 2014), which discussed the positive impact of inter-subjectivity in music on relaxation, empowerment, and interaction for both parents and infants. Indeed, CMT, being supportive in creating a space for

undemanding responsive inter-subjectivity, is viewed positively from a parental perspective. Additionally, our results support the need for psychosocial support for parents in early intervention programs, as emphasized by a meta-analysis deeming mere education insufficient (Benzies et al., 2013). Most intervention parents found it helpful to initiate and sustain singing with their infants. Some parents acknowledged the value of the music therapist's expertise in facilitating meaningful connections through music, highlighting that they might not have spontaneously thought of singing without the music therapist's guidance. Supportive elements varied among parents, including singing with the music therapist, understanding the importance of singing, receiving emotional support during shared moments, and the opportunity to experience their infant alongside the music therapist. The significance of the music therapist's undemanding approach is also emphasized, aligning with Shoemark (2017), who underscores the music therapist's role in supporting parents during NICU admission.

Additionally, intervention parents in our study emphasize the music therapy and the relationship with the music therapist as emotionally supportive. Emotional care, crucial in the NICU, emphasizes the therapeutic relationship for sharing presence and compassion (Bruschweiler Stern, 1998). Coughlin (2021) emphasizes Compassionate Family Collaborative Care, promoting emotional support for infants and parents through collaboration between professionals and parents. This approach resonates with parents' experiences of CMT in our study, suggesting that CMT offers vital emotional support, including comfort, calm, reassurance, and dedicated time for parents. One mother described how a particular song ("Trollmor") during music therapy sessions evoked deep emotional responses, serving as a cathartic expression of childbirth and challenging moments. Another parent found singing together with the music therapist liberating, especially when singing slightly sad lullabies. It became a way to articulate difficult emotions, providing relief. Yet another parent mentioned that singing during CMT sessions helped them manage sorrow. Similar emotional release through singing is reported by Palazzi et al. (2020), where a mother describes singing to her infant as an emotional release that made her feel better, and the music therapy intervention helped establish a more intimate connection between her and her infant. McLean (2016) emphasizes the emotional support provided by the music therapist in facilitating the parents' ability to engage with their infant through singing and music. Epstein and colleagues in their interview study (2023), describe how parents experience music therapy as an emotional haven.

In our study, several fathers found singing to their infant to be a significant bonding activity during the hospital stay and after discharge, which held deep meaning for them. Consistent with our findings, parents in the aforementioned studies also emphasized singing as a proactive contribution to their infant's wellbeing during the hospital stay. Singing was seen as something they could do for their infant (McLean, 2016; Palazzi et al., 2020).

In the control group, parents who sang generally described positive experiences and found it meaningful while interacting with their infant despite not receiving the same level of support from the music therapist as the intervention group. They felt a sense of cohesion within the family through parental singing, finding

joy in it even without closer musical guidance. All parents in the intervention group continued to sing at home. However, perhaps motivated by the study's recruitment information, this also applied to several parents in the control group. In this way, singing served as a bridge from the NICU to home life, strengthening family bonds. This aligns with the findings of Haslbeck et al. (2021), where parents reported that singing remained significant in family life many years later. This suggests that a CMT resource-oriented approach fosters emotionally nurturing interactions, empowering parents and strengthening family bonds over the long term. It also aligns with two other qualitative music therapy studies where parents report that they continue to use singing to their infant at home as a resource and parenting agency (Epstein et al., 2023), e.g., to soothe and facilitate self-regulation in their infant (Ghetti et al., 2021).

However, the most notable contrast between parents in the intervention and control groups was the lack of emotional support experienced by most control group parents. Since the variability in responses is much more constrained in the control group compared to the intervention group, generalizing the findings is challenging. However, if the material is representative, this disparity aligns with Winnicott's concept of a holding environment (Winnicott, 1971), which is essential for patient healing (Sanders and Hall, 2018). Creating such an environment is crucial in the NICU for fragile parents and infants (Stern, 1998). The emotional care provided by the music therapist facilitated healing and catharsis for intervention parents, whereas control parents lacked this support. Some intervention parents attributed the introduction of singing as a supportive tool, in their new role as parents, to the therapist, highlighting the latter's role in fostering meaningful connections through music.

Parents in both the intervention and control groups stressed the importance of integrating music therapy into neonatal care, citing its significance in supporting both infant development and parental transition into parenthood, consistent with findings by Haslbeck et al. (2021). Some participants suggested extending music therapy not only to NICU families but to all new parents, particularly emphasizing the value of singing to their infants during early parenthood. One mother even described singing to her infant as a healing intervention. Indeed, prenatal singing is associated with improved maternal mood, wellbeing, and mother-infant bonding (Wulff et al., 2021), as well as postnatal benefits such as reduced maternal stress, fewer neonatal crying episodes and less infantile colic, even in cases of prematurity (Persico et al., 2017).

In the Time Together program, Shoemark (2018) has devised a strength-based approach aimed at encouraging NICU parents to sing to their preterm infants after just one session with a music therapist. The findings from the control group in our study suggest that this approach may suffice for parents with a musical background who are already singing. However, some parents in the control group expressed that it would have been helpful to receive assistance in initiating singing and to have someone to share the experience with.

CMT sessions with the intervention group played a meaningful role in the process of becoming a parent, addressing NICU challenges and deepening the parent-child connection. This aligns with McLean et al. (2018), and with Epstein et al. (2023),

regarding on parents' experiences of music therapy in the NICU, highlighting infants' responses in musical interaction as validating and strengthening in the process of becoming a parent. In our study, some parents initially did not fully perceive their child as responsive, but singing played a transformative role, the infant appeared more human, it created intimacy and established a stronger connection. Experiences like these are significant in the NICU, offering parents a sense of comprehensibility and empowerment (Flacking et al., 2012). In this way our study aligns with Ettenberger et al. (2016), where parents refer to music therapy experiences as giving insights into how to relax and stimulate their infant through music, giving them a feeling of empowerment. Additionally, several intervention parents in our study highlighted the significance of participating in dialogues during music therapy sessions as supportive when recognizing their transition into parenthood.

Our results indicate that parents in the intervention group expressed how their interaction with the music therapist during music therapy sessions heightened their awareness of their infant's communicative skills. Furthermore, the intensity of experienced beneficial effects for the parents varied between the intervention and control groups. These findings are consistent with previous results from the Singing Kangaroo trial (Partanen et al., 2022). They emphasize the enhanced caregiver sensitivity resulting from the interactive qualities of CMT and suggest that this may be the driving component behind the enhancement of auditory processing in the brains of CMT infants compared to control infants. Rather than solely focusing on the amount of parental singing, they argue for a broader understanding of the effects of CMT, which includes improved parental self-esteem and sensitized caregiving. This is in line with the findings of Doiron et al. (2021) and Loi et al. (2017), who highlight the importance of enhanced parental self-esteem and sensitized caregiving for the wellbeing of both infants and parents, and their association with improved long-term infant development. Our results may indicate improving supporting the relationship between parents and infants during hospital care in the NICU. Although we didn't specifically ask about any negative influence on the relationship between infant and parents due to singing, it seems that the components in CMT are well-suited to embrace closeness for the whole family. Additionally these experiences of closeness through singing develop and reach out to the family's daily life when coming home after discharge. Therefore, we argue that CMT appears to be a relevant intervention in the NICU for enhancing self-esteem, fostering empowerment, and supporting in their transition to parenthood, which, in turn may contribute to the development of the premature infants. Despite its limitations, the methodological rigor and innovative approach contribute to a foundational understanding of parental experiences, which may inform future research and practice in neonatal care. Future research in this field could make an even deeper investigation about which are the core components in a child and family developmentally supportive music therapy such as CMT when it comes to supporting closeness and wellbeing for the whole family. Another important aspect to investigate is how the collaboration between health professionals and music therapists can support this. Future longitudinal research on parental and infant wellbeing is warranted, assessing SOC, bonding, attachment,

parental skills, and early interaction with appropriate, sensitive quantitative outcome measurements, as well as qualitative studies. Furthermore, more research is needed on follow-up music therapy after discharge to explore how CMT can support both the family and the infant's long-term development.

5 Conclusion

Although parents in the control group experienced joy and a certain degree of sense of coherence (SOC) when singing together with their infant, it was primarily the parents in the intervention group, who had participated in Creative Music Therapy (CMT), who experienced a strong sense of coherence SOC across all three of its categories: manageability, comprehensibility, and meaningfulness.

In conclusion, the SOC framework, with its components of manageability, comprehensibility, and meaningfulness, reflects the dynamic relationship between infants, parents, and their shared closeness. This connection resembles the synchronized interactions that occur during intimate moments, creating meaningful “now-moments” that strengthen their bond. This synchronicity, particularly in the stressful NICU context, may facilitate healing within the vulnerable family unit. This study explores how parental singing influences SOC in the NICU and beyond, offering insights for optimizing family-centered care for prematurely born infants. Even though the data is not sufficiently representative to draw general conclusions about how parental singing influences SOC in the NICU and beyond, it provides valuable insights into the potential benefits of integrating parental singing into family-centered care for prematurely born infants. To build on these findings, future studies should focus on examining the long-term effects of such interventions and evaluating their scalability. This could further enhance our understanding and inform the development of more comprehensive and effective care strategies in neonatal settings.

Data availability statement

The original contributions presented in the study are included in the article/[Supplementary material](#), further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving humans were approved by Swedish Ethical Review Authority (registry number 2014/1318-31; supplementary approval for interviews, registry number 2015/0120-32, supplementary approval registry number 2016/2362-32). The studies were conducted in accordance with the local legislation and institutional requirements. Written

informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

PH: Writing – original draft, Writing – review & editing, Project administration. FH: Writing – original draft, Writing – review & editing, Project administration. UÅ: Supervision, Funding acquisition, Writing – review & editing, Project administration. LE: Funding acquisition, Writing – original draft, Writing – review & editing, Project administration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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The development and face validity of the music therapy sensory instrument for cognition, consciousness, and awareness (MuSICCA)

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Severe brain injuries in children and young people can result in disorders of consciousness. This can pose significant challenges for the brain injury survivor as they may struggle to show awareness; for their family, who want to help their child to recover consciousness; and for the team providing treatment and care for them, who need an assessment that will inform optimal treatment and care planning. Currently, there is a paucity of fully validated behavioral tools to assess consciousness in 2–18-year-olds. Assessing awareness across this age range is challenging and complex due to neurodevelopmental changes that occur during maturation. This study evaluated the face validity of a music-based behavioral assessment for children and young people with disorders of consciousness. This is known as the Music therapy Sensory Instrument for Cognition, Consciousness and Awareness (MuSICCA). The study recruited 20 participants to compose a mixed cohort of music therapists, non-music therapy healthcare professionals and family members with lived experience of caring for a child or young person with a disorder of consciousness. These participants reviewed the MuSICCA and evaluated its suitability as an assessment of consciousness for use with children and young people. They provided feedback by rating their level of agreement with two statements and they also described the perceived strengths and limitations of the MuSICCA. The results showed substantial agreement among raters that the MuSICCA appears to be an assessment of consciousness and awareness, and that the MuSICCA appears to be suitable for use with children and young people. Its strengths include being rigorous, comprehensive, providing guidance and opportunity for caregiver involvement, its use of salience in stimulation, and its utility in supporting the wider clinical and care teams. The findings suggest that the MuSICCA may be a valuable assessment tool in providing treatment and care for children and young people with disorders of consciousness and their families.

KEYWORDS

MuSICCA, disorders of consciousness, music, assessment, face validity, pediatric, children, adolescents

1 Introduction

Acquired Brain Injury (ABI) may be fatal, severe, moderate, or mild. Severe ABI can result in Disorders of Consciousness (DoC) which are characterized by difficulties/problems with levels of wakefulness and awareness. The disorders within this category include Vegetative State (VS), also known as Unresponsive Wakefulness Syndrome (UWS), and Minimally Conscious State (MCS; [Royal College of Physicians, 2020](#)). The behavioral characteristics of VS/UWS comprise of spontaneous arousal and sleep-wake cycles; no sustained, reproducible purposeful or voluntary behavioral responses to sensory stimuli; and an absence of demonstrated awareness of self or others in their environment ([Multi-Society Task Force on PVS, 1994](#); [Royal College of Physicians, 2020](#)). The behavioral repertoire of VS/UWS suggests neurological activity that is reflexive and mainly at the sub-cortical level. The minimally consciousness state is characterized by diminished consciousness, but where the patient's behaviors demonstrate some awareness of themselves, in addition to behaviors that are reproducible and linked to specific environmental stimuli suggesting awareness of others ([Royal College of Physicians, 2020](#)). These behaviors suggest activity in the brain recruiting the cortex, and therefore, implying the presence of cognitively mediated responses.

Advances in medicine are leading to increasing numbers of people surviving severe brain injuries, leaving some with substantially impaired consciousness. The population of people with DoC have complex needs and multiple disabilities. Measuring responsiveness is a topic of considerable interest, as the information generated from the range of validated behavioral measures ([Seel et al., 2010](#)) is used to inform care and treatment planning by the whole multidisciplinary team. Inaccurate assessment continues to be a significant issue for the multidisciplinary teams working with people with DoC ([Wang et al., 2020](#)). The consequences of misdiagnosis include inadequate provision of care, treatment programmes that are not optimized for maximizing functional gains in areas of potential, poor identification of the patient's intentions to communicate, and insufficient evidence to support challenging decision-making around life support (withdrawal of hydration and nutrition) and resuscitation ([Ashwal, 2013](#); [Ashwal and Cranford, 2002](#)). Therefore, it is fundamental to develop and validate assessment tools to accurately assess this population, thus improving the care, treatment, and prognosis for people with DoC.

The process of assessing awareness in DoC is complex and made more challenging when assessing children and young people with these disorders. This added complexity is due to developmental factors, involving changes in language, cognition, and motor ability, which vary across age groups and within them. This can be a major challenge for clinicians and the family who need accurate assessment information regarding awareness and function to determine realistic expectations of the patient's abilities ([Menén Sánchez et al., 2023](#); [Alvarez et al., 2019](#)). Best practice guidelines advise that pediatric neurorehabilitation should be family-centered, and that family involvement can enhance the outcome of assessments ([Centers for Disease Control Prevention, 2018](#)). Treatments for children and young people should also draw on identity-based rehabilitation frameworks ([Perkins et al., 2022](#)). Music-based assessment protocols provide a plausible alternative

to language-based ones, as they do not rely on language processing ability. Furthermore, music is culturally ubiquitous and often used in pedagogical environments, leisure, and religious contexts ([Pool and Magee, 2016](#)). In adults, music is known to increase motivation ([Dimitriadis et al., 2023](#)), and influence awareness-related outcomes in DoC patients, including promoting arousal and attention ([O'Kelly et al., 2013](#)), boosting cognition ([Castro et al., 2015](#)) and improving measures of awareness ([Verger et al., 2014](#)).

At the time of writing, there is a paucity of fully validated awareness assessment tools for children and young people with DoC, although some measures have "preliminary validation" ([Molteni et al., 2023](#)). One assessment of awareness for adults is validated: the Music therapy Assessment Tool for Awareness in Disorders Of Consciousness (MATADOC). Its principal subscale has demonstrated good inter-rater reliability (mean = 0.83, SD = 0.11), good test-retest reliability (mean = 0.82, SD = 0.05), and good internal consistency ($\alpha = 0.76$; [Magee et al., 2014](#)). The MATADOC has fair to moderate concurrent validity with the criterion standard Coma Recovery Scale-Revised but measures awareness in different yet complementary ways due to its reliance on non-verbal music stimuli ([Magee et al., 2023](#)). The MATADOC protocol utilizes the presentation of a range of music stimuli, including those that are emotionally salient such as singing the patient's name as well as personally meaningful songs ([Amarí et al., 2017](#); [Menén Sánchez et al., 2023](#)). This supports its relevance for use with children also. The MATADOC was shown to provide a clinically useful protocol and measure for behavioral assessment and clinical treatment planning with children with DoC ([Magee et al., 2015](#)). However, it required some modifications and validation for use with this population.

Therefore, a pediatric version of the MATADOC was developed called the Music therapy Sensory Instrument for Cognition, Consciousness and Awareness (MuSICCA). It was developed clinically in consultation with a stakeholder group. This consisted of parents of children with DoC and professionals working in pediatric DoC settings. This multiprofessional group included educational psychologists, clinical psychologists, speech and language therapists, occupational therapists, physiotherapists, educators, and a global network of music therapists experienced in pediatric DoC who were MATADOC-trained. The MuSICCA protocol expands on that of the MATADOC and involves a minimum of six tasks using musical stimulation and non-stimulated observation periods of 3 min each before and after the stimulation period. Furthermore, the MuSICCA protocol offers family members the opportunity to be actively involved in delivering the procedures, thus maximizing salience within the stimuli presented and drawing on intimate knowledge of the child. The child is provided with opportunities to listen to music that is played live and based on the child's behaviors (e.g., breathing rate; motor behaviors), to show physical responses, vocalize, and make sounds or choices of music to be played by the therapist. Responses are rated across the motor, visual, auditory, communication, and arousal domains in 15 items. The MuSICCA is designed to provide an indicative diagnosis for children with DoC alongside other measures. It provides detailed information about their responses to stimuli to support the multidisciplinary treatment team and will contribute to the effort to reduce instances of misdiagnosis.

When testing a new measure to determine its validity and reliability, face validity is an important first step in the process. However, despite its importance, many studies fail to report on face validity testing in detail.

Validity might be broadly defined as all the quantitative and qualitative evidence we can muster to attest that a psychometric measure actually measures what it purports to measure. Streiner and Norman (2008) note that traditionally many textbooks have taught this topic in terms of the ‘three Cs’ namely *content*, *criterion*, and *construct validity*. Content validity is the extent to which a tool or measure taps into all the important elements of the construct of interest—such as whether a class test in mathematics samples all the major topics covered by the teacher in class. Criterion validity is the extent to which the measure correlates positively with other tests of a similar construct (convergent) or negatively with tests of a dissimilar (divergent) construct. Criterion validity can also refer to the ability of the measure to predict future outcomes. For example, we might test whether a measure of early infant temperament can predict subsequent development of emotional problems in adolescence. The third C, construct validity can be thought of as the extent to which all the data on a specific measure suggests that scores on that measure conform to or support our theoretical model of that construct. Some authors have gone so far as to argue that all forms of validity then constitute evidence for construct validity (Borsboom, 2005). However, a fourth important class of validity, and the focus of the present study is that of *face validity*.

Face validity is typically described as the extent to which a psychometric instrument appears acceptable, credible, sensible, reasonable, and plausible to the person responding to it. In a seminal paper on the topic (Mosier, 1947) proposed four major types of face validity; (i) validity by assumption, (ii) by definition, (iii) by hypothesis, and (iv) the appearance of validity. In an editorial on the issue of face validity three quarters of a century later (Allen et al., 2023) observe that contemporary definitions of face validity are almost entirely concerned with the latter—that the items in any measure appear valid to the test-takers. They identify Holden’s (2010) definition of face validity as the most up to date: “Face validity refers to a characteristic associated with a psychological test and its individual items. Distinct from more technical types of validity, face validity is the appropriateness, sensibility, or relevance of the test and its items as they appear to the person answering the test. That is, do a test and its items look valid and meaningful to the individual taking the test? More formally, face validity has been defined as the degree to which a test respondent views the content of a test and its items as relevant to the situation being considered (Holden, 2010, p. 637).”

In this respect it could be argued that the present study is *not* about face validity—at least not in the sense as defined by Holden. We are concerned here with a group of patients, children with disorders of consciousness who are by and large not able to respond to simple requests or instructions and incapable of giving their impressions and reactions to the items of the MuSICCA. Consequently, we made the decision to assess the face validity of the MuSICCA and its items by proxy using music therapists and other professionals experienced in working with children with disorders of consciousness, and the parents of such children. Allen et al. (2023) suggest that face validity has often been treated as less important than those aspects of validity that

lend themselves more readily to quantitative assessment. They also argue that it is an essential component of scale development and one which has particular importance for measures intended for use with children, clinical conditions, and disabled persons. In the present study, we worked with family caregivers, non-music therapy professionals working in pediatric DoC, and experienced pediatric music therapists to examine how they perceived the face validity of the MuSICCA.

This present study of face validity described here forms the first phase of a much larger and more detailed evaluation of the MuSICCA. The larger study will evaluate the MuSICCA’s construct validity, its inter-rater and test-retest reliability, and its clinical utility. For details about the overall research project, please refer to the published protocol (Pool et al., 2020) that has also received ethical approval from the Research Ethics Committee and Health Research Authority of the National Health Service of the UK (ID: 167534).

The research questions for this study of face validity are:

Does the MuSICCA have sufficient face validity to be an assessment of consciousness and awareness and suitable for use with children and young people?

What are its strengths and limitations from the perspectives of trained music therapists, other healthcare professionals, and family caregivers?

2 Method

2.1 Recruitment and description of participants

Twenty participants were recruited to evaluate the face validity of the MuSICCA. The selection of participants was carried out according to the following criteria:

2.1.1 Inclusion criteria

- The participant needed to have experience of working with or caring for children and young people with a DoC.
- The participants were one of the following:
 - a registered music therapist trained in the MATADOC or
 - a person with lived experience as a family caregiver of a child and young people with a DoC or
 - a non-music therapy healthcare professional.

2.1.2 Exclusion criteria

All members of the research team were excluded from being participants.

The music therapists were recruited from the database of MATADOC-trained professionals with experience of working with children with acquired brain injuries. The families and other healthcare professionals were recruited from a specialist pediatric rehabilitation center in the UK. These participants were invited to review the MuSICCA video demonstration. This consisted of

TABLE 1 Codebook excerpt from thematic analysis.

Raw data	Description	Initial theme	Superordinate theme	Domain
"Children should have parents present during the assessment"	Need for parental involvement during assessments	Involving caregivers	Benefits and risks of caregiver involvement	Utility
"A validated tool that will allow assessment and then go on to inform a treatment plan (this will/should offer reassurance to parents that assessment is meaningful and not an end state)"	An assessment tool that will inform goal-setting and seem useful to parents	Informs treatment and goal-setting	Has multifaceted utility	Utility
"The spectrum of ages covered is big. However, it doesn't specify if different responses should be expected according to the age"	Lack of guidance on age-appropriate expectations	Developmental specificity	Some further refinement needed	Utility
"Takes into account specific aspects of DoC in children"	It has been designed for use with children with DoC	Specificity	Rigor achieved through being evidence-based	Design

a 30-min verbal description accompanied by video excerpts of the procedure, followed by 30 min for a question and answer session. The video of the material is available by request from the corresponding author. The respondents were asked to provide feedback about the MuSICCA's face validity in response to two statements:

Statement 1: On initial review, the MuSICCA appears to be an assessment of consciousness and awareness.

Statement 2: On initial review, the MuSICCA appears to be suitable for use with children and young people.

Respondents independently rated their level of agreement or disagreement with each statement by selecting one of the following: strongly disagree, disagree, undecided, agree, and strongly agree. In addition to this, the respondents were asked for free text comments about the perceived strengths and limitations of the MuSICCA. Answers were submitted electronically via email, or in hard copy form depending on convenience. All anonymised response forms were printed as hard copies and stored securely in a locked cabinet.

The level of agreement between respondents regarding the statements was determined as a quantitative measure of face validity for the MuSICCA. In this study, the minimum level of agreement between reviewers was set at 75% for the MuSICCA to be considered to have face validity (Pool et al., 2020). This criterion for each statement was met if 75% of respondents agreed or strongly agreed. If this was achieved for both statements, then the MuSICCA would be considered ready for further testing for validity, inter-rater and test-retest reliability, and clinical utility. In this way, this study formed part of a more comprehensive process of developing and validating this new measure.

2.2 Data analysis

The quantitative data from the respondents' ratings to the statements were analyzed using percentage level of agreement calculated in Microsoft Excel, and Gwet's (2008) AC1 for measuring level of agreement between raters. This measure of agreement was selected *post-hoc* for its suitability for five-point agreement scale involving multiple raters and few items with the raw data indicating high agreement. This was calculated using R statistical software. The qualitative free text responses regarding the strengths and

limitations of the MuSICCA were analyzed using thematic analysis (Braun and Clarke, 2012). Coding was carried out by hand without the use of software. The purpose of thematic analysis in this study was to enable categorization of the strengths and limitations and detect relationships between themes. In this process, the free text comments from the questionnaires were presented in a table. Then, they were analyzed independently by two of the research team (JWP & WLM) using a theoretical (deductive) approach driven by their knowledge of the MuSICCA, the published literature in this area and the population of people with disorders of consciousness. Coding occurred at the latent level and was interpretive to allow analysis to examine the underlying theoretical ideas that shaped and informed the semantic content. Thus, initial codes (category themes) were created independently (JWP & WLM) and recorded in separate tables containing the original free text comments and initial codes. Then, the analysts met to discuss these initial codes until consensus was reached on a refined set of codes and themes. These were then reviewed by one of the original respondents (CW) to determine their fidelity, usefulness, relevance, and trustworthiness. The two analysts and the respondent discussed the latest codes and themes, refining these further to produce a final set of codes and themes. In this process, a simple thematic map of codes and themes was used to conceptualize the data patterns and the relationships between them. Codes and themes were merged to form broader, more comprehensive ones, while others maintained a discrete, narrower meaning. Table 1 shows a sample from the codebook. Then, the free text extracts were checked to consider whether these formed a pattern within each theme that was logical and consistent. The validity of the themes was considered in relation to the full data set and the thematic map was used to test these relationships. This process concluded with the definition and distillation of the themes and the organized thematic collation of data extracts for reporting on the findings. These were then related to the experience of the respondent (CW) who is a music therapist with experience of assessing and providing therapy for children and young people with disorders of consciousness and has trialed the MuSICCA for this study.

3 Results

Table 2 shows the respondents' roles in relation to children and young people with DoC and their levels of agreement with

TABLE 2 Respondents roles and levels of agreement with statements 1 and 2.

Respondent ID	Role	Response to statement 1	Response to statement 2
R1	Other healthcare professional	Agree	Strongly agree
R2	Other healthcare professional	Strongly agree	Agree
R3	Other healthcare professional	Agree	Agree
R4	Other healthcare professional	Agree	Agree
R5	Parent/carer	Strongly agree	Strongly agree
R6	Parent/carer	Strongly agree	Strongly agree
R7	Parent/carer	Strongly agree	Strongly agree
R8	Parent/carer	Strongly agree	Strongly agree
R9	Parent/carer	Strongly agree	Strongly agree
R10	Music therapist	Strongly agree	Strongly agree
R11	Music therapist	Strongly agree	Strongly agree
R12	Music therapist	Strongly agree	Strongly agree
R13	Music therapist	Strongly agree	Strongly agree
R14	Music therapist	Strongly agree	Strongly agree
R15	Music therapist	Strongly agree	Strongly agree
R16	Music therapist	Strongly agree	Strongly agree
R17	Other healthcare professional	Strongly agree	Strongly agree
R18	Music therapist	Strongly agree	Strongly agree
R19	Music therapist	Strongly agree	Strongly agree
R20	Music therapist	Strongly agree	Strongly agree

each statement. The respondent numbers are shown to enable referencing individual respondents in the thematic analysis.

The total of 20 respondents was comprised of 10 music therapists, five parents with lived experience of caring for their child with a DoC, and five other healthcare professionals working in pediatric neurorehabilitation. Seventeen respondents were from the UK, two from Ireland and one from Spain. They each had in excess of 3 years of experience of caring for someone with a DoC. The other healthcare professionals included a speech and language therapist, an occupational therapist, a physiotherapist, a psychologist, and an educator. The table shows that all 20 respondents gave a response of “agree” or “strongly agree” to either statement. No other levels of agreement “strongly disagree,” “disagree,” and “undecided” were given by the respondents.

3.1 Overall outcome

3.1.1 Statement 1: on initial review, the musicca appears to be an assessment of consciousness and awareness

The respondents showed 100% agreement that the MuSICCA appears to be an assessment of consciousness and

awareness, with 85% strongly agreeing with the statement (see [Figure 1](#)).

3.1.2 Statement 2: on initial review, the musicca appears to be suitable for use with children and young people

The respondents showed 100% agreement that the MuSICCA appears to be suitable for use with children and young people, with 85% strongly agreeing with the statement (see [Figure 2](#)).

Inter-rater reliability for both statements was also assessed using Gwet’s AC1. The Gwet’s AC1 coefficient was 0.64, indicating substantial agreement among the 20 raters [95% CI (0.64, 0.64), $p < 0.001$]. These results confirm strong reliability among raters, supporting the consistency of ratings.

3.2 Thematic analysis of the responses

[Table 3](#) shows the thematic map of the strengths and limitations of the MuSICCA.

Two domains entitled Utility and Design emerged as organizing categories and contained all other thematic categories. Superordinate themes arose relating to each of these domains. In the domain of Design were “Rigor achieved through being evidence-based” and “Provides comprehensive assessment.” In the domain of Utility were “Benefits and risks of caregiver involvement,” “Has multifaceted utility,” “Required training reduces accessibility,” “Some further refinement needed.” The superordinate theme “Has multifaceted utility” Incorporated the themes of “Administration,” “Clinical,” “Protocol,” and “Informs treatment and goal setting.” The theme “Clinical” captured codes such as “Acceptability” and “Being a strengths-based approach.” The superordinate theme “Some further refinement needed” captured themes “Guidance for implementation” and “Developmental specificity.”

The above themes are described within the domains in which they are situated. Identifiers (R1, R2, R3, etc...) are used to indicate which respondents commented on the theme or code described.

3.2.1 Design domain

3.2.1.1 Superordinate theme: rigor achieved through being evidence-based

This superordinate theme captures the comments describing the design of the MuSICCA as based on evidence (research and clinical experience) and indicating the logical justification for aspects of the design. Respondents considered the MuSICCA to be based on research and a “good understanding” of children and young people with DoC (R1, R7, R16), considering specific aspects of the population (R16), seemingly “based on the experience of using measures” in pediatric DoC (R1). It was also felt that, as the MuSICCA is based on the MATADOC and was developed in consultation with a global network of music therapists experienced in pediatric DoC, it draws on relevant clinical practice (R19).

The respondents commented about the assessment protocol, suggesting that it seemed “strong, well-planned” (R6) and “flows naturally” (R10, R14), and that it “enabled identification of level of awareness” (R9).

On initial review, the MuSICCA appears to be an assessment of consciousness and awareness.

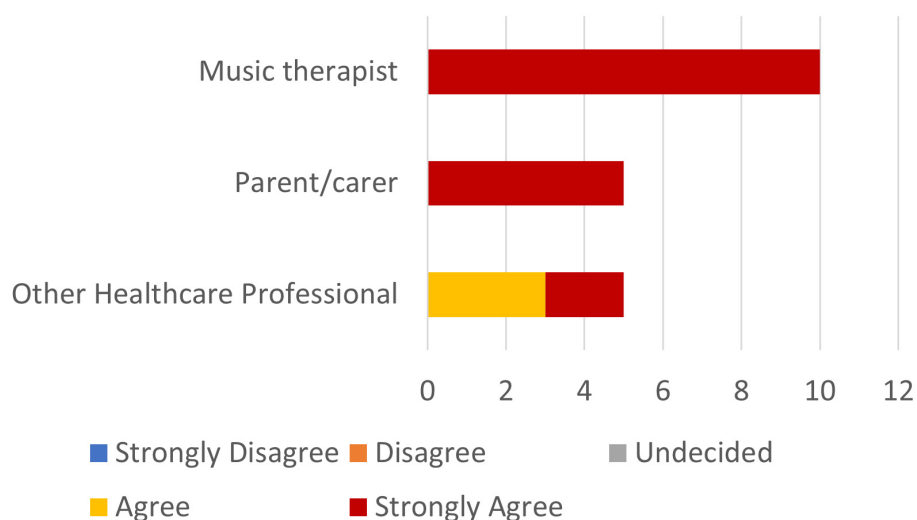


FIGURE 1

Stacked bar chart showing the number of ratings of levels of agreement with statement 1 by participants stratified by role.

On initial review, the MuSICCA appears to be suitable for use with children and young people.

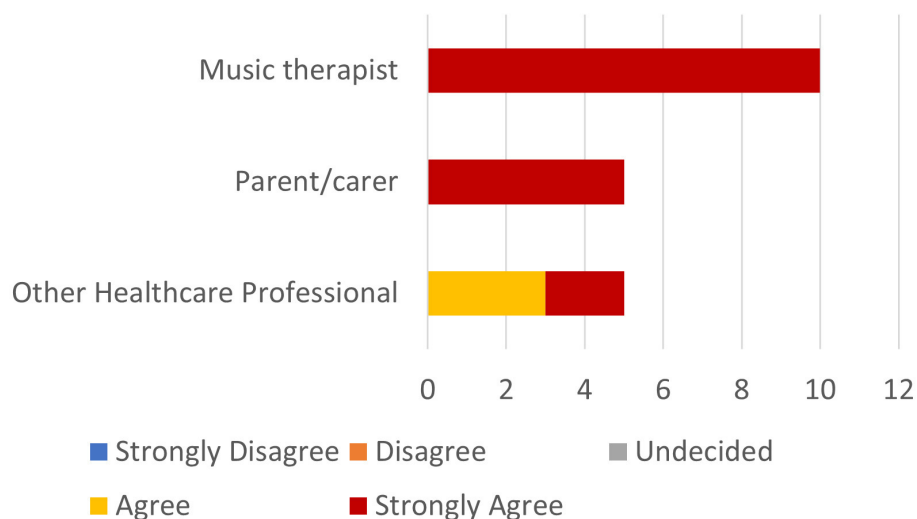


FIGURE 2

Stacked bar chart showing the number of ratings of levels of agreement with statement 2 by participants stratified by role.

In thinking about the MuSICCA's appropriateness for use in pediatric DoC, the respondents reported that it appeared "child-focused" (R6), using stimulation "that appeals to the children" (R7), "gives the opportunity for (responses) to take place" (R8), and involved a "reduced influence of complex language" (R12). They also mentioned that the MuSICCA's inclusion of parental voice as a stimulus enabled use of the "most salient auditory stimulus" (R16, R19) and including a child's family in assessment fostered closer

working with "those who know the child best and can advise on best-known music" (R19).

3.2.1.2 Superordinate theme: provides comprehensive assessment

Within the domain of "Design," this superordinate theme encapsulates the comprehensiveness of sensory stimulation available to a music-based assessment tool. The respondents

suggested that the MuSICCA protocol is thorough and covers all sensory modalities possible with musical stimuli (R1, R5, R9, R13). They highlighted the inclusion of the newly added “vibrotactile element to assess responsiveness” as a useful benefit (R11, R12, R15, R16, R20). “Gathering the pre-trauma story of the child’s relationship with music” was mentioned as a strength (R6). The “methodology” of the protocol appeared comprehensive and “considered virtually all aspects of the situation for the individual” (R9).

3.2.2 Utility domain

3.2.2.1 Superordinate theme: provides comprehensive assessment

The comprehensiveness of the MuSICCA was captured in this superordinate theme from the perspective of clinical utility. Respondents stated that the inclusion of the vibrotactile element allowed for touch to be used strategically within the assessment. They reported that the MuSICCA appeared to provide a “thorough assessment of children and young people who might present with a DoC” (R1, R5, R9, R13) and it will “provide a thorough picture of how a young person is presenting” (R6, R13).

3.2.2.2 Superordinate theme: benefits and risks of caregiver involvement

This superordinate theme represents both the strengths of caregiver involvement and some concerns expressed by the respondents. The possibility to include caregivers during the assessment was seen generally as a strength with one respondent suggesting that “children should have parents present during assessment” (R7). Respondents considered that parents might wish to be present and, therefore, the available guidance for including them in the assessment allows for caregivers to occupy a role (R3, R12) in their child’s assessment through providing stimulation and child-specific knowledge that may “inform approaches within assessment sessions” (R20). However, one respondent acknowledged the need to address the duty of care to the caregivers when including them in assessments of their child (R6). Another noted that caregivers may not follow the guidance and, thus, may affect the assessment outcomes (R14).

3.2.2.3 Superordinate theme: has multifaceted utility

The greatest number of comments were contained in this superordinate theme, captured by four themes (Administration, Protocol, Clinical, and Informs Treatment and Goal-Setting).

3.2.2.3.1 Theme: administration

Comments within this theme refer to the rating form and documentation. These were considered to appear “user-friendly, clear, and simple” (R1, R13, R15) and able to be “completed in a timely manner” (R3, R4). The respondents highlighted the visual nature of the form and documentation and reported that this seemed helpful (R10, R16, R18). The electronic format of the rating form was seen as a strength and timesaving for clinicians (R11, R13, R15, R16, R18). The use of visual graphs was seen as a benefit for reporting on the assessment outcomes (R10, R11, R16). The respondents also liked the idea of the rating form feeding into a report to support the clinician when preparing reports (R11, R16).

TABLE 3 Thematic map of strengths and limitations of the MuSICCA.

Domain	Superordinate theme	Theme	Sub-theme/code
Design	Rigor achieved through being evidence-based		
	Provides comprehensive assessment (design)		
Utility	Provides comprehensive assessment (utility)		
	Benefits and risks of caregiver involvement		
	Has multifaceted utility	Administration	
		Clinical	Acceptability
			Being a strengths-based approach
		Protocol	
		Informs treatment and goal setting	
	Required training reduces accessibility		
	Some further refinement needed	Guidance for implementation	
		Developmental specificity	

3.2.2.3.2 Theme: protocol

This theme captures the flexibility of the protocol for providing stimuli. Respondents suggested that the protocol allows for personally salient stimuli and familiar music that are “adaptable for individuals make this tool seem more likely to elicit responses” (R2) and increase the “chance for child engagement” (R3, R4). The respondents suggested that this adaptable use of music and sounds enables age-appropriate stimuli to be chosen that are based on the interests of the child or young person. For example, the respondents mentioned the use of nursery rhymes, children’s familiar songs for young children, theme tunes and sounds from computer games for older children and young people as well as popular music (R4, R9, R16).

There were also comments on the protocol as a whole. Respondents suggested that it appeared to flow very easily (R10) and that its adaptable nature helped with assessment when attention might be limited (R14). The use of motor responses was seen as a strength (R16).

3.2.2.3.3 Theme: clinical

Comments that centered on the clinical utility of the MuSICCA were encapsulated within this theme. These can be grouped into two sub-themes of Acceptability and Being a Strengths-based Approach. Relating to Acceptability, respondents felt that it had a “clear procedure based on the MATADOC” (R20) and that there are “a range of settings in which it can be used” (R6). However, the time burden of conducting four assessments was also mentioned (R6).

The respondents viewed the MuSICCA as “strengths and abilities-based rather than a ‘test’” (R12, R16, R17). They highlighted this aspect of the measure and its relevance for treatment planning (R6, R10, R16). One respondent also noted that the MuSICCA protocol and refined rating system, utilizing the highest-rated response, reduced the impact of sensory impairments on the outcomes of the assessment (R12).

3.2.2.3.4 Theme: informs treatment and goal-setting

This theme refers to the utility of the MuSICCA as an assessment tool that supports the team to develop goals and leads on to treatment. The respondents commented on specific characteristics of the MuSICCA, including its ability to record stimuli parameters (R10), its utility as a repeated measure for tracking progress and highlighting change (R10, R12, R17). One respondent mentioned the need to think carefully about reducing the number of sessions from 4 and how this might affect the diagnostic validity of the measure (R5). The MuSICCA was considered to complement other assessment tools through its music-based approach (R1) and, thus, support the multidisciplinary team through adding important information to build a comprehensive picture of the child or young person. The potential value of the MuSICCA to caregivers was also mentioned. One respondent stated that it appeared to be a “tool that will allow assessment and then go on to inform a treatment plan (this will/should offer reassurance to parents that assessment is meaningful and not an end state)” (R6).

3.2.2.4 Superordinate theme: required training reduces accessibility

This superordinate theme relates to the accessibility of the MuSICCA as a music-based assessment that is conducted by a music therapist. One respondent highlighted the need for specific training and felt that “therapists using this tool would likely need quite a lot of individual teaching to be able to administer” (R2).

3.2.2.5 Superordinate theme: some further refinement needed

Captured in this superordinate theme were the suggestions respondents provided around improvements and concerns. Concerns included comments about the reliance on the assessor’s memory for recording the responses to stimuli (R16), and the observation that the protocol may not be able to be delivered exactly the same way each time due to the fact that live music is used in the protocol (R17). Many of the suggestions relate to the protocol instructions and the assessors’ manual. Respondents felt that clearer guidance was needed on the presentation of visual stimuli in the protocol, specifically with reference to the positioning and timing of the movement of the visual stimuli (R3, R4). Clarification regarding the verbal command was also suggested for improvement (R10, R14, R20). The respondents commented that clarification in the guidelines is needed regarding the timing of the sessions, specifically referring to time of day and time after a rest period (R8, R9), to “ensure consistency of comparability” (R9). The respondents also suggested that the guidelines should contain clarification regarding expectations of responses at each age (R10, R12, R14, R20). One respondent highlighted the need to ensure comments

by parents, carers, other staff are given significant attention to help build a comprehensive picture of the child or young person (R7).

4 Discussion

This study shows that the MuSICCA has sufficient face validity to be considered an assessment of consciousness and awareness that seems appropriate for use with children and young people. The 100% agreement between reviewers for both questions provides clear evidence for this statement. The answers from the respondents demonstrate the qualities of the MuSICCA in its design, and in its clinical utility as an assessment of awareness for children and youth with DoC.

The respondents highlighted the rigorous nature of the MuSICCA and that it is grounded in evidence. The adaptations for making it appropriate for use with children, the assessment protocol, and the use of salient stimuli (with potential inclusion of family) contribute to this rigor. These aspects of its design are congruent with recommendations for using music with children with DoC (Menén Sánchez et al., 2023; Bower et al., 2021) and enhance the MuSICCA’s appropriateness and acceptability as an assessment tool.

Comprehensiveness was perceived by the respondents in this study as a particular strength in both its design and the breadth of its utility. This quality helps the assessor feel confident that the assessment is using all opportunities available to reveal signs of awareness in the patient. For the multidisciplinary team, this comprehensiveness enhances the relevance of the assessment information and can inform the approaches of other therapies (physiotherapy, speech and language therapy, and occupational therapy) for individual children. This can also support medical teams in their evaluation of the positive and negative effects of pharmacological treatments. The comprehensiveness and rigor of the behavioral assessment tool contribute to its diagnostic accuracy and to its ability to mitigate diagnostic confounds and to inform medicolegal evaluation (Zasler, 2024).

The use of music as a stimulus in the MuSICCA recruits widespread neural activation and cross-domain activity. These transient but powerful arousal-inducing (O’Kelly et al., 2013) and cognition-boosting effects (Schlaug et al., 2005; Castro et al., 2015) of music on the child’s brain are the key to unlocking the child’s potential to show awareness.

The MuSICCA addresses some of the recommendations set out in the practice guideline update for DoC (Giacino et al., 2018) including raising arousal prior to and during the assessment and using validated measures. This study is the first step in the process of producing a valid and reliable music-based assessment tool for children with DoC.

A particular strength of the MuSICCA is the protocolised involvement of family caregivers, if available, thereby maximizing the salience of the stimulation. This, to our knowledge, is the first assessment of DoC to actively involve caregivers, who are best placed to advise on stimuli that are the most familiar and salient, and who also hold detailed knowledge about the child’s behaviors, personality, preferences, and experiences. Indeed, the auditory stimulus of a parent’s or sibling’s voice within the session

may be the most familiar auditory stimulus for children and of itself increase arousal and responsiveness. Empowering parents by including them in the protocol delivery helps to enhance their own understanding of their importance as part of the team as their voice is the most salient stimulus helping to facilitate the child to show a response. Their knowledge about their child is critical to finding salient music and their involvement in the session enables greater accuracy in the interpretation of behaviors (Formisano et al., 2019). This might be understood to be somewhat contradictory to current common practice where caregivers' interpretations of behaviors in the DoC patient are given secondary, or even less, importance. However, this fits practice recommendations for the care of people who have a DoC (Leonardi et al., 2024, p. 231) and broader guidelines for family-centered pediatric neurorehabilitation. Involving the family in an assessment that is highly personalized may even help with their coping and the adjustment to the changes in their family's life. Including family members in this way also helps to build relationships with the healthcare providers. This is invaluable in their journey through the rehabilitation process and can facilitate discussion of multidisciplinary assessment findings with the family. Thus, the involvement of the family in the process may also support the multi-professional team in their work to support the child and the family.

The context of family-centered neurorehabilitation is important when considering face validity for this assessment tool since face validity may be defined as the degree to which the test appears relevant to the situation being considered. The broader context of this situation is one of optimizing care for a child or young person with highly complex needs and beyond merely providing diagnostic information. Involving the family in the protocol draws them immediately into the multidisciplinary team network of support and sits within the best practice guidelines that neurorehabilitation should be family-centered (Royal College of Physicians, 2020; Jenkin et al., 2023).

A recent study (Gosseries et al., 2023) investigating the needs, quality of life and emotional distress of caregivers of people with DoC showed that the needs for health information, professional support and involvement in care were the three highest rated by caregivers. This indicates the importance of these needs to caregivers of people with DoC. The MuSICCA addresses these needs by providing important information regarding responses to sensory stimuli, informing the multidisciplinary team to optimize their support for the patient and family, and proactively involving the caregivers in their child's rehabilitation.

The MuSICCA process helps to build a continuous thread of identity from before injury to the present, and to a future post-injury identity. This reflects existing music therapy brain injury rehabilitation protocols for adults that capture past and present musical identities to inform re-building of identity in treatment planning (Tamplin et al., 2016). Establishing the child's musical biography and the family's musical culture in the MuSICCA process can support psychological adjustment for the child and their family, aligning with models of family resilience during times of adversity (Perkins et al., 2022). The personalized nature of the MuSICCA assessment may help to mitigate the family's experience of losing the child's personhood (Løvstad et al., 2018) as part of a complex

grief experience and the family's ambiguous loss. The process of participating in the MuSICCA protocol offers opportunities for the family to embody some psychological support (Leonardi et al., 2024) as it focuses on the child's personhood. The feedback of difficult news to family members regarding the diagnosis of DoC may also be mitigated since the parent has participated in the assessment and has developed a working relationship with the music therapist. Furthermore, the feedback from the MuSICCA highlights the child's individuality and identity. In clinical practice, feedback to the family often occurs with other team members who have completed complementary assessments and who have commented that the MuSICCA better captures the sense of the child and their personality.

Involvement in the MuSICCA protocol offers family members opportunities to witness moments of attunement during clinical improvisation. These moments occur when the music therapist responds to the child's breathing rate, movements, or vocalizations, and can lead to parental requests for family music therapy, guidance on how to interact musically with their child or discussions about parenting styles. This may further impact rehabilitation since nurturant parenting styles are associated with better outcomes for young people after an acquired brain injury (Root et al., 2016) and since finding meaningful ways of interacting can offer hope for families (Magee and Bowen, 2008; Menén Sánchez et al., 2023). The findings from this study indicate the potential utility of the MuSICCA not only for music therapy assessment, but for the entire multidisciplinary team, particularly in the absence of other developmentally relevant assessments for children and young people with DoC. The MuSICCA may offer a strengths-based assessment that supports the child or young person to show how responsive he/she is. As the protocol is personalized with a degree of adaptability to individual preference (Amari et al., 2017), salience can be maximized thus optimizing possibilities for responses. The information it generates informs the whole team's understanding of the child and how to optimize treatment, therapy, and care to meet the child's needs and set appropriate goals.

4.1 Limitations of the present study

The purpose of the present study of face validity was to gain a sense of whether there should be any further changes made to the MuSICCA prior to initiating more rigorous and detailed testing in the larger study that will follow. This larger, more rigorous study will evaluate the tool's construct validity, reliability (inter-rater and test-retest) and clinical utility. Despite this, it is important to acknowledge some of the limitations of the present study of face validity. The sample size for the face validity testing may be small when compared with evaluations of other types of validity that involve inferential statistical tests. This small sample size may have limited the credibility of the research findings. However, face validity has been poorly reported in previous research and there is a lack of reported methodologies with sufficient detail in both the DoC and music therapy literature in this area. Other studies have varied widely in their sample size. For example, Bower et al. (2023) recruited 10 healthcare professionals with experience working with DoC populations. In other fields of health research, a recent face

validity study (Christian et al., 2025) has involved a sample size of <20 participants. A review of studies of face validity (Allen et al., 2023) showed a sample size range across studies of 7–76 participants. This present study's sample size falls within that range but is toward the lower end, and a larger sample size may have increased its rigor.

The composition of the sample may contain some bias, being made up of mainly music therapists, some non-music therapy healthcare professionals working in pediatric ABI settings, and some families of children with ABI. While this diverse group aided representativeness regarding the stakeholders of the MuSICCA, the larger proportion of music therapists may be considered to introduce bias into the sample. A justification for this is that it was necessary to limit the number of families that would be burdened by participation in the present study at a time when they might be experiencing significant psychological stress due to their child having a brain injury. Additionally, the key stakeholder group for the assessment of the tool are the clinicians who would be using it—the music therapists. They were considered most suitable to give specific feedback on the strengths and weaknesses of the MuSICCA and would be able to provide useful recommendations or suggestions for adaptations based on their unique knowledge of providing music interventions for children with DoC. Therefore, it was important to capture their opinions most of all. Thus, the sample was biased toward them. Despite the rationale given, the issue of bias would be addressed by having a larger sample in which each stakeholder group has equal numbers of participants.

The statistical analysis selected for this study was limited by the small sample size and the intention to focus on the opinions about the MuSICCA of the participants recruited rather than generalizing beyond the sample. The study of face validity is largely subjective as a construct and is based on the purpose of the individual tool and as such there is no one statistical index that measures face or content validity (Portney and Watkins, 2009). Therefore, face validity of the MuSICCA was considered to be sufficient if agreement between participants reached at least 75% agreement. In an editorial by Allen et al. (2023), the authors reviewed some studies that looked at face validity with the aim of providing some clarity regarding face validity and how it could be measured. Their review demonstrated that there is a lack of clarity around measuring face validity and, hence, a paucity of statistical recommendations for face validity in the literature. A larger sample size would have enabled the selection of more rigorous inferential statistics to increase the external validity of the results.

Further validation studies will be required in the future to test the psychometric properties of the MuSICCA, including predictive validity, and versions in other languages.

4.2 Conclusion

There is a paucity of assessment tools for pediatric DoC in the acute and sub-acute settings as a whole and this affects the entire clinical and care teams, not merely the

music therapists. The consequences of misdiagnosis are very serious and discussions about the level of awareness have relevance for decision-making regarding withdrawal/continuation of hydration and nutrition, treatment/goal planning, designing, and providing optimal stimulation for rehabilitation, and access to rehabilitation in general. So, the whole team is affected by this need to accurately assess a child's level of consciousness following severe ABI. The MuSICCA—a music-based assessment tool for pediatric DoC—is uniquely designed to provide the optimal conditions to assess consciousness in children, and it possesses features that give the child the best possible chance of showing responses. The information from the assessment is directly relevant to the wider clinical team. The findings of this study of its face validity suggest that the MuSICCA possesses sufficient face validity in its current form to undergo more rigorous evaluation of its validity, reliability, and clinical utility with a larger sample size. This study, with perspectives from medical and therapeutic professionals as well as family caregivers, shows that the MuSICCA can be used to inform the whole team assessment of consciousness, goal setting and treatment planning for each child. Furthermore, it does so in a way that involves families who will potentially find the tool to be accessible and acceptable, particularly at a time of significant emotional stress and trauma for the family. The use of this music-based assessment tool can inform and support the whole multidisciplinary team to improve care and treatment for children with DoC.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by East of England - Essex Research Ethics Committee, Health Research Authority, National Health Service of the UK. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

JP: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. WM: Formal analysis, Methodology, Writing – original draft, Writing – review & editing. RS: Methodology, Writing – original draft, Writing – review & editing. CW: Writing – original draft, Writing – review & editing.

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