REVIEW ARTICLE

Fetuses can Listen, Learn, and Remember: We Need to be Cautious about What and How We Say It!

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Abstract

The fetal auditory system becomes functional during mid-gestation or possibly even earlier. Existing data show that fetuses can respond to maternal voice and different types of music, both vocal and instrumental. The ability to receive and transmit sound waves, and then recognize and retain some memory of these auditory stimuli could possibly be one of the most important developmental sensory milestones that we need to learn about. Unfortunately, we still have limited evidence for the precise role and timing of prenatal sound simulation. There is a need for methodologically strong, randomized controlled trials with rigorously designed interventions and standardized reporting measures. We may need to compare different durations and types of musical (sound) intervention. At a minimum, these interventions can improve maternal–fetal bonding and family-centered outcomes. Any evidence of neurodevelopmental gains would be an important scientific/medical advancement. In certain conditions such as neonatal abstinence syndrome, emerging evidence suggests that early, *in utero* intervention with music therapy can be helpful; these findings bring hope for new therapeutic tools to enhance the neurological development of at-risk fetuses. Considering that prenatal music exposure might have positive effects on the fetus and newborn infant, we need carefully conducted studies of intrauterine neurosensory organization with long-term follow-up.

Keywords: Fetus, Mother's cardiotocographic parameters, Music therapy, Neonatal behavior, Neonatal neurological system, Newborn, Pregnancy, Rhythm, Sound, Speech.

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Key Points

- In terms of structure, the fetal hearing system is recognizable at early as 3–6 weeks of pregnancy. Functionally, the inner, middle, and outer ear are sufficiently developed at 24–25 weeks' gestation to identify/distinguish between vibroacoustic stimuli.
- Fetuses and newborn infants can respond to maternal voice across her abdominal wall. They also respond to different types of music, both vocal and instrumental.
- *In utero* exposure to music and speech induces stimulus-specific memory traces in the fetus. These stimuli may promote brain growth and possibly even short- and long-term cognitive gains.
- There is some evidence that music therapy can help in disorders such as neonatal abstinence syndrome. Possibly, timely *in utero* intervention may also enhance neurological development in other high-risk conditions.
- We need to carefully evaluate the immediate and long-term effects of music therapy on intrauterine neurosensory organization.

Introduction

The fetus is exposed to a variety of auditory stimuli from as maternal heart sounds, voice, respiratory and bowel sounds, and environmental stimuli.[1] Since hearing is acquired early during pregnancy, there is a possibility that planned antenatal exposure to music might have a have a role in fetal learning.[2,3] Considering that music also has a calming effect on the mother with few known adverse effects,[4] There is curiosity as to whether music could/should be a routine intervention during pregnancy.[5] In this article, we have reviewed the information available on the impact of prenatal exposure to music on the growing fetus. We have assimilated

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information from an extensive review of the literature utilizing key terms in multiple databases including PubMed, EMBASE, and Science Direct.[6,7] To avoid bias in the identification of studies, keywords were short-listed *a priori* from anecdotal experience and PubMed's Medical Subject Heading (MeSH) thesaurus.[8–12]

The Beginnings of Sound Reception in Fetal Development

At the time of birth, a newborn baby is largely equipped with all the senses available to an adult.[13] The ability to receive and transmit stimuli in sound waves is important and matures rapidly in the second trimester.[14] Training becomes possible in later pregnancy.[15]

The development of the auditory system begins between 3 and 6 weeks of pregnancy.[16] At 24–25 weeks' gestation, the structures of the inner, middle, and outer ear are sufficiently developed to recognize vibroacoustic stimuli.[17] In the developing central nervous system (CNS), auditory stimuli can promote the maturation of the temporal lobe regions that help recognize low-frequency sounds.[18] The fetus hears sounds coming from the mother's body first, such as those emanating from her cardiac contractions, blood flow in larger vessels, intestinal peristalsis, or airflow in the respiratory tract. The hearing threshold between 27 and 28 weeks' gestation is about 40 dB.[19,20] The fetuses then respond to sounds with a frequency of 250–500 Hz.[21,22] Ongoing myelination of nerve fibers in the CNS continues to improve impulse conduction.[23] Between 29 and 30 weeks' gestation, the fetus can perceive higher-frequency sounds such as the mother's voice, an infant's cry, or an alarm.[24] During the 34–35 weeks period, fetuses no longer seem to get alarmed with sounds that previously caused arousal. They begin to respond to sounds with frequencies of 1000–3000 Hz. At term, the hearing threshold is 13.5 Hz.[25]

During pregnancy, extraneous sounds are usually first transmitted from the air, through the abdominal wall, the uterus, and finally to the amniotic fluid and the head of the fetus.[26] Intra-uterine sounds might be more important. The sound of the mother's heartbeat is 25 dB above basic noise, dominating the fetal environment.[24] Her voice is heard almost 4 times louder in the womb than outside.[27] Most sounds in the fetal environment are dominated by lower frequencies.[28] Energy above 0.5 kHz is attenuated by 40–50 dB. The fetus easily detects vowels, whereas consonants, which are higher in frequency and less intense than vowels, are largely unavailable.[28]

The Importance of Music in the Prenatal Period

Music stimulation of a growing fetus is plausibly a positive stimulus to promote a range of positive outcomes for both the mother and the fetus, the child.

Emotional Bonding and Stress Reduction

Long-standing cultural practices view music as a likely catalyst for emotional connection, allowing a mother to establish a deeper bond with her unborn child.[29] Soothing songs and singing lullabies have been encouraged as a means to decrease stress and promote relaxation and emotional well-being. The harmonious vibrations of music can help to create a serene environment, fostering a sense of peace and tranquility for both the mother and baby.

Language Development and Cognitive Stimulation

Prenatal music and speech form stimulus-specific memory traces during the fetal period,[30,31] thereby stimulating brain growth, cognitive development, and long-term neural effects.[32] Fetuses start responding to music in the second trimester.[33] Singing by pregnant women provides auditory stimulation to their unborn child.[33,34]

Language acquisition and development of hearing could be enhanced by rhythmic melodies.[33,34] Cognitive abilities and habituation for music can be demonstrated in fetuses and young infants.[35] Arguably, the ability to discriminate speech stimuli *in utero* can promote acquisition of native language fundamentals during fetal life.[36] Neonates prefer their mother's voice and also the language their mothers used while pregnant with them. [37–39]

Sleep Regulation and Relaxation

In newborn infants, soothing melodies and instrumental compositions can help establish healthy sleep patterns in both the mother and a newborn infant.[40] Similarly, music can promote natural sleep in both the pregnant mother and her fetus by reducing stress.[41] As shown in late preterm infants, these effects could possibly be mediated by the release of endorphins in the CNS.[40,42,43]

Bonding and Maternal Heartbeat

In the antenatal period, mother's heartbeat is a familiar and comforting rhythm for the baby.[44] Rhythmic melodies and instrumental compositions can simulate maternal heartbeat and promote mother–fetal bonding, which might extend into the postnatal period.[29,45–47]

Enhanced Sensory Development

Music can promote the development of the fetal sensory pathways and sensory integration.[31] Vibrations caused by music can be felt by the fetus, creating a multisensory experience that involves hearing, movement, and consequently, touch with the uterine walls, the umbilical cord, and even its own face.[42,48,49] The movements indicate their engagement with the auditory stimuli, thereby preparing them for the postnatal sensory experiences.[30]

Maternal–Fetal Interactions

Fetal activities can be observed and followed since early pregnancy.[50] The maturation of these activities is closely related to the development of the sense organs even *in utero*. Fetal motor activity can be identified as early as at 6–8 weeks' gestation.[51] At 12 weeks, the movements can now be characterized as "kicking," "fetal rotation," "opening/closing of the fist," "nodding," "sucking-like oral activity," and "reactions to touch."[51] As pregnancy progresses, these activities become more frequent, mature with larger amplitude and improved coordination of muscle groups.[52] These movements are brief but the frequency progressively increases toward term gestation.[53]

In 2015, Marx and Nagy showed that fetuses reacted with arm, head, and oral movements when the mother touched the belly.[54,55] Her voice evoked head and arm movements. Third-trimester fetuses showed more yawning (regulatory), resting (crossed arms), and independent touch (hands touching body) responses to stimuli compared with those seen during the second trimester. Two years later, the same investigators used 3- and 4-dimensional ultrasound to examine fetal responses to tactile stimuli on maternal abdomen. Touching the belly by the mother, father, and a stranger was compared. In the control group, the fetal response was examined while at rest, without touching the abdomen. When the mother touched her abdominal wall, the third-trimester fetus touched the uterine wall for significantly longer periods than those in the second trimester. The third-trimester fetuses showed stronger/longer responses when touched by their mother. These differential responses in older fetuses may reflect the maturation of the CNS and the emergence of proprioceptive self-awareness.[54]

In 2021, Nagy at al.[56] examined fetal responses to maternal touch and voice. The sensorimotor competencies of the fetus clearly suggest that communication readiness begins to develop prior to birth. In response to maternal abdominal touch, fetuses show responses that have been variably perceived by different observers as cross-communication or self-stimulation. When the mother touched her abdominal wall and spoke in a gentle voice, fetal movements paused for some time. Similar responses were seen during conversations with a third person (interpersonal conversation). The fetuses showed a longer mouth-opening time during these period. The results suggest that third trimester fetuses can distinguish between interactive and non-interactive external stimuli and also distinguish these from incidental, other interactions.

In 2012, Kisilevsky et al.[57] examined the impact of auditory stimuli on fetal heart rate (HR) and heart movements in diabetic and overweight pregnancies. Fetuses in overweight pregnancies responded to their mother's voice with increased HR. These altered reactions to the maternal voice in diabetic pregnancies may indicate relatively immature nervous or auditory system, increased sensorineural threshold, lower levels of thyroid hormones, or iron deficiency in the mother.

Lee et al.[58] compared fetuses in women with hypertension vs controls upon hearing maternal voice. In the maternal hypertension group, the fetuses showed increased HR upon listening to the mother's voice. However, if the voice was recreated, there was no increase in fetal HR. The differential responses of the fetus to the maternal voice in pregnancies complicated by maternal hypertension may reflect a functional increase in the sensorineural threshold or a delay in the maturation of the auditory system, which may indicate functional differences during fetal life or subtle differences in the development of the CNS. Recent observations of maternal voice recognition provide evidence for residual memory and learning in healthy fetuses. We still need to investigate higher-order auditory processing in maternal hypertension, which is associated with reduced and/or compromised uteroplacental blood flow.

Knowledge of memory is based largely on observing newborns who seem to recognize their mother's voice. A few studies have assessed the biological processes that facilitate fetal responses to the maternal voice *in utero*.[59] Fetal HR and motor activity have been recorded at 36 weeks' gestation while pregnant women read aloud from a neutral passage.[60] Compared with the resting period, fetuses showed reduced motor activity and slower HR within 10 seconds after the onset of maternal speech. Subsequent analyses showed that the fetal response was modified by both maternal and fetal factors. The behavior of fetuses whose mothers were previously awake and talking was analyzed; a period of fetal orientation can be measured when a mother starts reading aloud. Compared with women who rested and remained silent, the fetuses reacted with increased HR and movements. The fetal response was also dependent on the initial variability of the fetal HR; the greatest response was shown during periods of low variability, when the mothers had been resting and were silent. The results indicate that fetal response is influenced by both maternal and fetal conditions, which has an impact on understanding the fetus's learning of the mother's voice in neutral settings.[60] The reaction to sounds was also compared with those of premature infants. In high-risk infants, the cardiac and motor responses were recognizable at 30 weeks' gestation. At 33 weeks, high-risk infants showed increased HR compared with low-risk fetuses. The results indicate that both low- and high-risk premature infants begin to respond to sounds at the same gestational age. The varied responses observed during pregnancy in the high-risk group most likely indicate diversified functional development of the auditory system.[61]

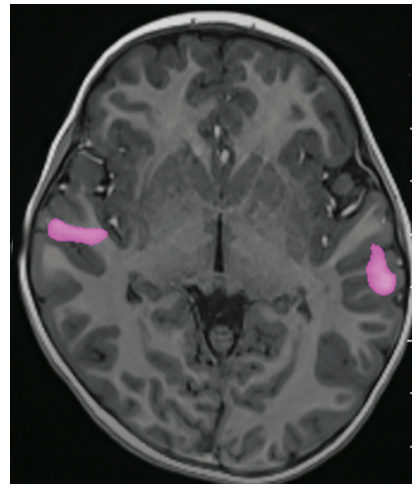

Fig. 1: Sounds activate specific temporal lobe regions in children: A passive-listening functional-magnetic resonance imaging (fMRI) task comprised of a series of words and non-language noise induced bilateral activation in the posterior superior temporal gyri. This particular fMRI image is from a 5-year old with a hypothalamic hamartoma who underwent fMRI for surgical planning; sounds were delivered using headphones. The image shows that we now have the technology to study the impact of sounds on specific areas of the brain and can study developmental changes in young infants

The maturation of the fetal response to music was characterized in the last trimester of pregnancy using a 5-minute piano recording of Brahms' Lullaby played at an average volume level of 95, 100, 105, or 110 dB.[62] Within 30 seconds of turning on the music, the youngest fetuses (28–32 weeks of gestation) showed an increase in HR limited to the two highest dB levels. During pregnancy, the threshold level decreased and a shift in response from acceleration to deceleration was observed at lower dB levels, indicating attention to the stimulus. During 5 minutes of music, fetuses over 33 weeks of gestation showed a sustained increase in HR. Changes in body movement occurred at 35 weeks of pregnancy. These findings suggest a change in the processing of complex sounds around the 33rd week of gestation, with response limited to the acoustic properties of the signal in younger fetuses, while episodes of focusing were observed in older fetuses.[62]

An attempt was also made to examine the impact of lullabies sung by mothers on the bond and behavior of newborns. There was no significant effect on prenatal attachment. Only the postnatal bond was significantly greater in the group of singing mothers 3 months after birth. In the same group of singing mothers, episodes of newborn crying in the first month, as well as infantile colic, were significantly less common. At the same time, a reduction in the frequency of night awakenings was observed. It can be concluded that singing lullabies by mothers can improve the bond between mother and child. It may also have a positive impact on the behavior of newborns and thus reduce the stress level in the young mother (Fig. 1).[63]

The Mozart Effect

There are two complementary communication systems in humans—language and music and functional imaging studies suggest these are processed in nearby brain regions. Music affects many aspects of human behavior, encourages social interactions and promotes trust and cooperation within groups of culturally compatible individuals. Music acts on the limbic system, is rewarding and motivating, and can facilitate learning and memory.[64–66]

Oxytocin is vital to the attachment between infants and parents through early contact and interaction can influence developing brain functions in infants culminating in behavioral changes in the child.[67,68] Maternal behavior is mediated by oxytocin, a neuropeptide synthesized in the paraventricular nucleus (PVN).[69–71] The central nucleus of amygdala (CeA) expresses oxytocin receptors and interacts with the reward circuit to motivate maternal behaviors.[72–74] Experiments in rats have shown that maternal behaviors are influenced by environmental factors in pregnancy; being reduced by stress and enhanced by enriched environments. The "Mozart effect" influenced the licking of offspring by mother rats and such offsprings had decreased behavioral anxiety and stress responses as adults.[75,76] Increased maternal oxytocin levels lead to greater affectionate contact behaviors in mothers following mother–infant contact.[67] The changes in rearing behaviors due to music are due to modulation of the oxytocinergic system by activation of oxytocin receptors and neuromodulation of the oxytocinergic system.[72,74,77]

Placental Programming

Hereditary and environmental stimuli are assimilated as placental epigenetics which influence the fetal development. Fetal brain development in the third trimester is impacted by plasticity and hence neurobehavioral phenotype can be altered by prematurity. Prenatal music stimulation has a positive epigenetic effect on fetus by virtue of placental programming.[78]

The auditory cortex is located in the posterior-medial part of Heschl's gyrus. This region corresponds with the Brodmann's area 41, a highly plastic epigenetic area vital to prenatal learning.[79,80] Acoustic environments influence the functional organization and processing capabilities of the auditory cortex.[81,82]

Music Therapy and Memory

Musical intervention has a therapeutic role in dementia or Alzheimer's disease because music elicits feelings and memories.[83] Music therapy induces plastic changes in brain networks, thereby facilitating brain recovery processes and modulation of emotions and communication.[84] Hence, it is a propitious modality of rehabilitation.

It has been reported that listening to classical music, specifically selections from Mozart can result in a temporary improvement in cognitive functions like abstract/spatial reasoning tests.[85] The "Mozart Effect" is attributed to the arousal due to the pleasure of listening to music, rather than a direct impact on cognitive ability.[86,87]

Influence of Music on Fetal Cardiotocographic Parameters

Although music has long been recognized for its effect on human emotions, physiological responses, and overall well-being, the mechanisms remain largely unknown.[88] Machin and Dunbar proposed that activation of the endogenous opioid system, including β-endorphins and encephalins, which are known to foster and maintain social bonds, improve mood and reduce the sensation of pain, are a possible mechanism.[89] In women with a low- or high-risk pregnancy, and in non-stress tests (NSTs), music appeared to reduce maternal anxiety.[90–92]

During pregnancy, maternal stress can affect fetal development, including altered fetal HR patterns.[93] In a recent systematic review, Shimada et al.[94] noted improved maternal relaxation, decreased anxiety, psychosocial stress and depression, reduced pain, increased maternal bonding with her fetus, improved sleep quality, improved blood pressure profiles, lower fetal HR, and lower need for medications after surgery. Music therapy during the pre- and perinatal periods may be benefit both the pregnant women and their newborns infants. Maul et al.[95] performed a systematic review to assess maternal mental health outcomes after musical intervention from 14 randomized controlled trials (RCTs) including 2,375 pregnancies. They showed reduced maternal stress, anxiety, and depression. These data are consistent with the beliefs that modulation of maternal physiological parameters through music may influence fetal well-being.[5]

Neural processing of music involves an extremely complex and extensive network of cortical and subcortical structures which integrate auditory, sensory motor, and cognitive functions as well as emotional changes.[4] As expected from our understanding of the neurosensory development of the fetal auditory system, initial responsiveness to different sound frequencies begins around 23 weeks' gestation. By 24 weeks, fetuses demonstrate a startle response to vibroacoustic stimulation. These responses are seen consistently at 28–30 weeks.[33,96,97] Indeed, music may improve fetal autonomic responses and learning/memory formation.[30,32,98]

Evidence from RCTs

Effect of Music Exposure on FHR

In a prospective RCT, James et al.[99] examined whether prenatal exposure to a musical stimulus altered fetal behavior and whether these responses persisted after birth into the newborn period. Using an exposure-learning model, music was played to 10 fetuses via a headphone on the maternal abdomen and 10 controls had the headphone without sound. All fetal studies took place within 72 hour prior to elective delivery. After delivery, all 20 newborns were exposed to the same music on postnatal days 3–5. Computerized assessment of FHR and activity was documented and neonatal behavioral states were recorded. For the 1st hour of the study, neonates that had had *in utero* exposure showed higher mean HR and showed longer periods of high HR variation. These findings, however, were not statistically different from controls. However, by the 4th hour, the exposed fetuses began to show significantly more HR variation ($p = 0.04$) and more state transitions ($p = 0.01$) compared with unexposed fetuses. These effects persisted into the neonatal period with the same music stimulus evoking more state transitions ($p = 0.01$) and leading to longer awake states ($p = 0.05$). Thus, prenatal exposure to music altered the fetal behavior that persisted after birth.

Granier-Deferre et al.[100] showed that repetitive prenatal exposure to specific melodies influenced neonatal auditory perception and memory that was retained for 3–4 days to 6 weeks. In the test arm of the study, fetuses were given precisely controlled exposure to a descending piano melody twice a day during weeks 35–37 of gestation. After 6 weeks, cardiac responses of 25 exposed infants and 25 naive control infants to the descending melody and to an ascending control piano melody were examined during quiet sleep. The melodies had precisely inverse contours, but similar spectra, identical duration, tempo and rhythm, and thus, nearly identical amplitude envelopes. All infants displayed a significant change in HR. In exposed infants, the descending melody evoked a cardiac deceleration that was twice larger than the decelerations elicited by the ascending melody and by both melodies in control infants.

Brillo et al.[101] randomized 30 healthy mother–fetus dyads in a 1:1:1 ratio to one of three groups: (1) fetuses were submitted to pre-listening phase (33^0–36^3 week) and listening sessions during 4 NST; (2) fetuses were submitted to listening sessions during 4 NST only; and (3) 4 NST without any listening. Mean fetal HR, fetal HR accelerations/decelerations, fetal movements, and uterine contractility were assessed. The 1st group fetuses, who had heard a particular piece of music during previous sessions, showed significantly increased HR accelerations and movements during the music listening session of the last NST. Uterine contractions did not change in frequency. They concluded that fetuses respond to familiar but not to unknown music.

Catalgol and Ceber Turfan randomized 100 (50 intervention, 50 control) primipara women. The NST was applied in 36–38 weeks' gestation.[102] During the test, music was played to the intervention group, while the control group received routine care. The music group showed lower mean scores of State Anxiety Inventory during NST. Acceleration, mean number of fetal movements and fetal HR reactivity were significantly higher in the intervention group. Thus, music therapy in pregnant women decreased maternal anxiety and had positive effects on NST findings.

Soylu et al.[103] showed that music affected vital signs, fetal movements, and lowered the state and trait anxiety levels during NST in pregnant women. In 74 (37 music and 37 control group) pregnant women, post-music exposure HRs were lower than the pre-procedure values ($p < 0.001$). The groups did not differ in baseline fetal HR, variability, fetal movement, presence/number of accelerations-decelerations, and NST parameters. The number of fetal movements was higher in the music group than controls ($p < 0.001$). The state anxiety inventory scores were lower in the music group than controls ($p < 0.001$).

In a cross-over RCT, Oh et al.[104] tested the effects of musical intervention on maternal anxiety, fetal HR, and testing time during NST. Sixty pregnant women in 28–40 weeks' gestation were randomly assigned to either an experimental (n = 30) or a control group (n = 30). The experimental group showed significantly lower scores in state anxiety than controls. There two groups showed no difference in systolic blood pressure and HR. Baseline fetal HR was significantly lower and frequency of acceleration was significantly increased in the experimental than in the control group.

Estrella-Juarez enrolled 343 full-term pregnant women in a RCT and divided them into three parallel groups: (1) music therapy intervention (n = 104), (2) virtual reality intervention (n = 124), and (3) controls (n = 115).[105] The interventions were delivered during NST in the third trimester and during labor. Measures included the Spielberger State-Trait Anxiety Inventory, maternal blood pressure, maternal and fetal HRs, and labor and birth outcomes. Women in the music therapy and virtual reality groups had less anxiety after NST ($p < 0.001$), and the women were more likely to have a reactive NST ($p < 0.001$) than controls. Following completion of NST and intervention, music therapy and virtual reality groups had lower systolic blood pressure ($p < 0.001$), diastolic blood pressure ($p < 0.001$), and maternal HR ($p = 0.003$) than controls. Furthermore, fetuses in the control group were more likely to show non-reassuring fetal HR tracings than those in the music therapy and virtual reality groups, respectively ($p = 0.004$).

Effect of Prenatal Music Exposure on Neonatal ECG and Neuro-behavioral Response

In a pilot study, Lang et al. showed that newborns displayed distinct reactions to maternal voice at 2 and 5 weeks after birth on a physiological level and identifiable with ECG and EEG changes.[106] Basic memory traces were formed *in utero* and shaped neonatal autonomic and neuronal reactions to speech and voice stimuli. Newborns exposed to nursery rhymes prenatally showed distinctly different reactions than those not exposed. The authors concluded that fetal brain is "programmed" for the predicted postnatal environment and maternal voice.

In an open-labeled RCT, Arya et al.[3] evaluated the effects of antenatal music exposure in healthy primigravidae on the behavior of their term appropriate-for-date newborns, assessed using 7 clusters of the Brazelton Neonatal Behavioral Assessment Scale (BNBAS). Primigravida mothers aged 19–29 years who had a singleton pregnancy, at ≤20 weeks' gestation, and did not have any chronic medical diseases or significant hearing impairment, were randomized to listen to a pre-recorded music cassette for approximately 1 hour/day in addition to standard antenatal care (intervention arm) or standard care only (control arm). Perinatal factors with adverse effect on neonatal behavior were deemed as protocol violations. One hundred and twenty-six newborns (music group) and 134 (controls) were tested. Infants of mothers exposed to music during pregnancy performed significantly better on 5 of the 7 BNBAS clusters. The maximal beneficial effect was seen with respect to orientation (ES 1.13, 95% CI: 0.82–1.44, $p < 0.0001$) and habituation (ES 1.05, 95% CI: 0.53–1.57, $p = 0.0001$). Prenatal music exposure to mother significantly and favorably influenced neonatal behavior.

As seen above, many systematic reviews were of mixed methodological quality and showed ambiguous efficacy of auditory stimulation of preterm infants. Hence, a meta-analysis of several studies was performed.[107–132] The authors evaluated the impact of parallel and cluster-RCTs on preterm infants <37 weeks' gestation during hospitalization, and also studied the effects on parents who were involved in the intervention. The evaluated interventions included any live/recorded music or vocal stimulation for >5 minutes, administered >3 times, by a music therapist, a parent, or a healthcare professional, and these were compared with standard care. Many studies had to be excluded from this analysis because of inadequate data.[42,133–191]

The authors studied 25 trials including 1,532 infants born at 25–36 weeks' gestation and 691 parents (21 parallel-group RCTs, 4 cross-over RCTs). The intervention did vary in type, delivery, frequency, and duration; music and voice that were typified as calm, soft, musical parameters in lullaby style were often integrated with mother's voice. There was considerable variability in the risk of bias in included studies. Music/vocal interventions reduced HRs in infants during intervention (mean difference, MD, –1.38, 95% CI: –2.63 to –0.12; $p = 0.03$; 1014 infants; 11 studies; moderate-certainty evidence) and after intervention (MD –3.8, 95% CI: –5.05 to –2.55; $p < 0.00001$; 903 infants, 9 studies; high-certainty evidence). There were no reported adverse effects. There was no change in oxygen saturations during care. Similarly, there was no difference in infant development (Bayley Scales of Infant and Toddler Development with the cognitive composition score; motor composition score; and the language composition score). Parents showed no difference in the incidence of anxiety or depression.

Evidence from Non-RCTs

Kumar et al.[41] examined the impact of music therapy for feto-maternal monitoring in nine pregnant women. They found that fetal HR increased from 146 to 169 beats per minute after exposure to music from headphones paced around the mother's abdomen. The increase in HR was consistent with a reactive NST. Music could serve as a means of communication with the fetus through sounds and voices. Caressing the fetus through the abdomen, producing soft and melodic sounds, using lights and vibrations were pleasant for the fetus.

In a prospective observational study in 100 uncomplicated pregnant women, between 32 and 41 weeks gestation, Erkun Dolker and Basar showed significant differences between the music-exposed and control groups in terms of mean numbers of acceleration, deceleration, and reactive NST results ($p = 0.001$).[192]

Gebuza et al.[193] showed a significant reduction in the number of uterine contractions, increased FHR accelerations and variability and increased fetal movements following exposure to classical music during NST in 48 pregnant women in their third trimester. Their recent study involving 30 (classical music during NST) and 60 (NST only) pregnant women between 27 and 41 weeks of gestation, confirmed their previous findings that classical music therapy could be a non-invasive, affordable method to improve fetal well-being.[193,194]

A Polish study showed a positive correlation between uterine contractility, fetal movements, and increasing music rhythm. There was no influence on fetal HR.[195]

Lee et al.[196] reported that musical intervention on fetal HR altered fetal Doppler between 30 and 38 weeks' gestation. Mean (±standard deviation) fetal movements during fixed singing activity (0.7 ± 0.79) were lower than during irregular singing (1.73 ± 1.37). This showed that fetal movement and HR could be stabilized by singing fixed songs to promote well-being and establish maternal–fetal bonding.

Future Directions

We still need more evidence to ascertain the precise role of timing of prenatal sound simulation. Methodologically strong RCTs involving this concept with rigorously designed interventions, consistent outcomes, and standardized reporting measures are needed. Future studies may include comparisons of different durations and types of musical (sound) intervention. Future studies can focus on specific effects of different types of music including instrumental music compared with vocals, classical vs metal and maternal vs other voices. It has been shown to promote maternal–fetal bonding.[49,79] Studies are needed for better understanding of the mechanisms by which music affects the growing brain, intrauterine neurosensory organization, and changes during development.[195] Changes to the physical environment, like darkening the room and decreasing visual and auditory stimuli in the infant's surroundings.

Music therapy may also be useful in specific maternal/fetal conditions such as drug dependance given the beneficial effects of music therapy in infants with neonatal abstinence syndrome postnatal conditions. Neonatal abstinence syndrome is potentially an important area for study; the numbers in the United States are staggering.[197,198] The incidence of NAS in the US started increasing in 2000 and nearly doubled between 2010 and 2017.[199,200] We need carefully conducted studies to determine the prenatal impact of maternal substance use on the fetus.[201]

Conclusion

Prenatal sound stimulation including music and mother's speech influences the development and function of the fetal/neonatal neurological system. Fetuses seem to respond to various forms of music that they have been exposed to. Further studies can be beneficial.

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References

1. Yetkin AK, Gunes B, Erbas O. Prenatal auditory stimulation and its significance for newborns. J Exp Basic Med Sci 2023;4(2):96–103. DOI: 10.5606/jebms.2023.1051.
2. Mastnak W. Perinatal music therapy and antenatal music classes: Principles, mechanisms, and benefits. J Perinat Educ 2016;25(3): 184–192. DOI: 10.1891/1058-1243.25.3.184.
3. Arya R, Chansoria M, Konanki R, et al. Maternal music exposure during pregnancy influences neonatal behaviour: An open-label randomized controlled trial. Int J Pediatr 2012;2012:901812. DOI: 10.1155/2012/901812.
4. Chang MY, Chen CH, Huang KF. Effects of music therapy on psychological health of women during pregnancy. J Clin Nurs 2008;17(19):2580–2587. DOI: 10.1111/j.1365-2702.2007.02064.x.
5. Ji C, Zhao J, Nie Q, et al. The role and outcomes of music therapy during pregnancy: A systematic review of randomized controlled trials. J Psychosom Obstet Gynaecol 2024;45(1):2291635. DOI: 10.1080/0167482X.2023.2291635.
6. (Netherlands) E. Excerpta Medica dataBASE Amsterdam, The Netherlands Elsevier (Netherlands); 2024. Available from: https://www.elsevier.com/products/embase.
7. Elsevier. ScienceDirect Amsterdam, The Netherlands: Elsevier B.V.; 2024. Available from: https://www.sciencedirect.com/.
8. NLM. Welcome to Medical Subject Headings Bethesda, Maryland, USA: National Library of Medicine; 2024. Available from: https://www.nlm.nih.gov/mesh/meshhome.html.
9. NLM. MeSH (Medical Subject Headings) Bethesda, Maryland, USA: National Library of Medicine; 2024. Available from: https://www.ncbi.nlm.nih.gov/mesh/.
10. Enkin MW, Jadad AR. Using anecdotal information in evidence-based health care: Heresy or necessity? Ann Oncol 1998;9(9):963–966. DOI: 10.1023/A:1008495101125.
11. Pannucci CJ, Wilkins EG. Identifying and avoiding bias in research. Plast Reconstr Surg 2010;126(2):619–625. DOI: 10.1097/PRS.0b013e3181de24bc.
12. NLM. PubMed User Guide: National Library of Medicine; 2014. Available from: https://pubmed.ncbi.nlm.nih.gov/help/#how-do-i-search-pubmed.
13. Streri A, de Hevia MD. How do human newborns come to understand the multimodal environment? Psychon Bull Rev 2023;30(4):1171–1186. DOI: 10.3758/s13423-023-02260-y.
14. Litovsky R. Development of the auditory system. Handb Clin Neurol 2015;129:55–72. DOI: 10.1016/B978-0-444-62630-1.00003-2.
15. Sukta B. Rozwój zmysłów w okresie prenatalnym. Studia Paedagogica 2020;13:37–46. DOI: 10.24917/22992103.13.4.
16. Ritter KE, Martin DM. Neural crest contributions to the ear: Implications for congenital hearing disorders. Hear Res 2019;376: 22–32. DOI: 10.1016/j.heares.2018.11.005.
17. Anthwal N, Thompson H. The development of the mammalian outer and middle ear. J Anat 2016;228(2):217–232. DOI: 10.1111/joa.12344.

18. Puddu M, Fanos V. Developmental programming of auditory learning. J Pediatr Neonatal Pers Med 2012;1(1):59–66. DOI: 10.7363/010111.
19. Lary S, Briassoulis G, de Vries L, et al. Hearing threshold in preterm and term infants by auditory brainstem response. J Pediatr 1985;107(4):593–599. DOI: 10.1016/s0022-3476(85)80030-5.
20. Meyer-Bisch C. [Measuring noise]. Med Sci (Paris) 2005;21(5):546–550. DOI: 10.1051/medsci/2005215546.
21. Gelat P, David AL, Haqhenas SR, et al. Evaluation of fetal exposure to external loud noise using a sheep model: Quantification of in utero acoustic transmission across the human audio range. Am J Obstet Gynecol 2019;221(4):343 e1–343 e11. DOI: 10.1016/j.ajog.2019.05.036.
22. Moller H, Pedersen CS. Hearing at low and infrasonic frequencies. Noise Health 2004;6(23):37–57. PMID: 15273023.
23. Morell P, Quarles RH. The Myelin Sheath. In: Siegel GJ, Agranoff BW, Albers RW, Fisher SK, Uhler MD, editors. Basic Neurochemistry: Molecular, Cellular and Medical Aspects. 6 ed. Philadelphia, Pennsylvania, USA: Lippincott-Raven; 1999.
24. Querleu D, Renard X, Versyp F, et al. Fetal hearing. Eur J Obstet Gynecol Reprod Biol 1988;28(3):191–212. DOI: 10.1016/0028-2243(88)90030-5.
25. Cylkowska-Nowak M. Społeczne znaczenie muzyki i ruchu we wczesnym rozwoju dziecka. Polskie Pismo Muzykoterapeutyczne 2021;8(9):66–74. Available from: https://am.katowice.pl/assets/media/db5b123f03db439795cf993f37a581bb.pdf.
26. Guven SG, Tas M, Bulut E, et al. Does noise exposure during pregnancy affect neonatal hearing screening results? Noise Health 2019;21(99):69–76. DOI: 10.4103/nah.NAH_18_19.
27. Teie D. A comparative analysis of the universal elements of music and the fetal environment. Front Psychol 2016;7:1158. DOI: 10.3389/fpsyg.2016.01158.
28. Gerhardt KJ, Abrams RM. Fetal exposures to sound and vibroacoustic stimulation. J Perinatol 2000;20(8 Pt 2):S21–S30. DOI: 10.1038/sj.jp.7200446.
29. Wulff V, Hepp P, Wolf OT, et al. The effects of a music and singing intervention during pregnancy on maternal well-being and mother-infant bonding: A randomised, controlled study. Arch Gynecol Obstet 2021;303(1):69–83. DOI: 10.1007/s00404-020-05727-8.
30. Movalled K, Sani A, Nikniaz L, et al. The impact of sound stimulations during pregnancy on fetal learning: A systematic review. BMC Pediatr 2023;23(1):183. DOI: 10.1186/s12887-023-03990-7.
31. Chorna O, Filippa M, De Almeida JS, et al. Neuroprocessing mechanisms of music during fetal and neonatal development: A role in neuroplasticity and neurodevelopment. Neural Plast 2019;2019:3972918. DOI: 10.1155/2019/3972918.
32. Partanen E, Kujala T, Naatanen R, et al. Learning-induced neural plasticity of speech processing before birth. Proc Natl Acad Sci USA 2013;110(37):15145–15150. DOI: 10.1073/pnas.1302159110.
33. Hepper PG, Shahidullah B. The development of fetal hearing. Fetal Matern Med Rev 1994;6(3):167–179. DOI: 10.1017/S0965539500001108.
34. Arenillas-Alcon S, Ribas-Prats T, Puertollano M, et al. Prenatal daily musical exposure is associated with enhanced neural representation of speech fundamental frequency: Evidence from neonatal frequency-following responses. Dev Sci 2023;26(5):e13362. DOI: 10.1111/desc.13362.
35. Muenssinger J, Matuz T, Schleger F, et al. Auditory habituation in the fetus and neonate: An fMEG study. Dev Sci 2013;16(2):287–295. DOI: 10.1111/desc.12025.
36. Ruben RJ. The ontogeny of human hearing. Acta Otolaryngol 1992;112(2):192–196. DOI: 10.1080/00016489.1992.11665402.
37. DeCasper AJ, Fifer WP. Of human bonding: newborns prefer their mothers' voices. Science 1980;208(4448):1174–1176. DOI: 10.1126/science.7375928.
38. Moon C, Cooper RP, Fifer WP. Two-day-olds prefer their native language. Infant Behav Dev 1993;16(4):495–500. DOI: 10.1016/0163-6383(93)80007-U.
39. Mehler J, Jusczyk P, Lambertz G, et al. A precursor of language acquisition in young infants. Cognition 1988;29(2):143–78. DOI: 10.1016/0010-0277(88)90035-2.
40. Pocwierz-Marciniak I, Harciarek M. The effect of musical stimulation and mother's voice on the early development of musical abilities: A neuropsychological perspective. Int J Environ Res Public Health 2021;18(16):8467. DOI: 10.3390/ijerph18168467.
41. Kumar S, Sengupta A, Anand S. Novel method of feto-maternal monitoring using music therapy - A non-stress test. Int J Adv Res Comp Sci 2011;2(2):472–474. DOI: 10.26483/ijarcs.v2i2.427.
42. Qiu J, Jiang YF, Li F, et al. Effect of combined music and touch intervention on pain response and beta-endorphin and cortisol concentrations in late preterm infants. BMC Pediatr 2017;17(1):38. DOI: 10.1186/s12887-016-0755-y.
43. Sanli Y, Goke Arslan G, Aypar Akbag NN, et al. Effects of music on sleep quality and comfort levels of pregnant women. J Perinat Med 2022;50(4):467–475. DOI: 10.1515/jpm-2021-0551.
44. Ullal-Gupta S, Vanden Bosch der Nederlanden CM, Tichko P, et al. Linking prenatal experience to the emerging musical mind. Front Syst Neurosci 2013;7:48. DOI: 10.3389/fnsys.2013.00048.
45. Ettenberger M, Bieleninik L, Epstein S, et al. Defining attachment and bonding: Overlaps, differences and implications for music therapy clinical practice and research in the neonatal intensive care unit (NICU). Int J Environ Res Public Health 2021;18(4):1733. DOI: 10.3390/ijerph18041733.
46. Longhi E. Emotional response in mother-infant musical interactions: A developmental perspective. Behav Brain Sci 2008;31(5):586–587. DOI: 10.1017/S0140525X08005402.
47. Trehub SE. The developmental origins of musicality. Nat Neurosci 2003;6(7):669–673. DOI: 10.1038/nn1084.
48. Phillips-Silver J, Trainor LJ. Feeling the beat: Movement influences infant rhythm perception. Science 2005;308(5727):1430. DOI: 10.1126/science.1110922.
49. Standley J. Music therapy research in the NICU: An updated meta-analysis. Neonatal Netw 2012;31(5):311–316. DOI: 10.1891/0730-0832.31.5.311.
50. Luchinger AB, Hadders-Algra M, van Kan CM, et al. Fetal onset of general movements. Pediatr Res 2008;63(2):191–195. DOI: 10.1203/PDR.0b013e31815ed03e.
51. Einspieler C, Prayer D, Marschik PB. Fetal movements: The origin of human behaviour. Dev Med Child Neurol 2021;63(10):1142–1148. DOI: 10.1111/dmcn.14918.
52. Marsal K. Ultrasonic assessment of fetal activity. Clin Obstet Gynaecol 1983;10(3):541–563. PMID: 6360464.
53. Ryo E, Kamata H, Seto M, et al. Reference values for a fetal movement acceleration measurement recorder to count fetal movements. Pediatr Res 2018;83(5):961–968. DOI: 10.1038/pr.2017.328.
54. Marx V, Nagy E. Fetal behavioral responses to the touch of the mother's abdomen: A frame-by-frame analysis. Infant Behav Dev 2017;47:83–91. DOI: 10.1016/j.infbeh.2017.03.005.
55. Marx V, Nagy E. Fetal behavioural responses to maternal voice and touch. PLoS One 2015;10(6):e0129118. DOI: 10.1371/journal.pone.0129118.
56. Nagy E, Thompson P, Mayor L, et al. Do foetuses communicate? Foetal responses to interactive versus non-interactive maternal voice and touch: An exploratory analysis. Infant Behav Dev 2021;63:101562. DOI: 10.1016/j.infbeh.2021.101562.
57. Kisilevsky BS, Gilmour A, Stutzman SS, et al. Atypical fetal response to the mother's voice in diabetic compared with overweight pregnancies. J Dev Behav Pediatr 2012;33(1):55–61. DOI: 10.1097/DBP.0b013e31823e791e.
58. Lee CT, Brown CA, Hains SM, et al. Fetal development: Voice processing in normotensive and hypertensive pregnancies. Biol Res Nurs 2007;8(4):272–282. DOI: 10.1177/1099800406298448.
59. Groome LJ, Mooney DM, Holland SB, et al. Behavioral state affects heart rate response to low-intensity sound in human fetuses. 1999;54(1):39–54. DOI: 10.1016/s0378-3782(98)00083-8.
60. Voegtline KM, Costigan KA, Pater HA, et al. Near-term fetal response to maternal spoken voice. Infant Behav Dev 2013;36(4):526–533. DOI: 10.1016/j.infbeh.2013.05.002.

61. Kisilevsky BS, Pang L, Hains SM. Maturation of human fetal responses to airborne sound in low- and high-risk fetuses. Early Hum Dev 2000;58(3):179–195. DOI: 10.1016/s0378-3782(00)00075-x.
62. Kisilevsky S, Hains SM, Jacquet AY, et al. Maturation of fetal responses to music. Dev Sci 2004;7(5):550–559. DOI: 10.1111/j.1467-7687.2004.00379.x.
63. Persico G, Antolini L, Vergani P, et al. Maternal singing of lullabies during pregnancy and after birth: Effects on mother-infant bonding and on newborns' behaviour. Concurrent Cohort Study. Women Birth 2017;30(4):e214–e220. DOI: 10.1016/j.wombi.2017.01.007.
64. Zatorre RJ, Salimpoor VN. From perception to pleasure: Music and its neural substrates. Proc Natl Acad Sci USA 2013;110 Suppl 2(Suppl 2):10430–10437. DOI: 10.1073/pnas.1301228110.
65. Koelsch S. Investigating the neural encoding of emotion with music. Neuron 2018;98(6):1075–1079. DOI: 10.1016/j.neuron.2018.04.029.
66. Harvey AR. Links between the neurobiology of oxytocin and human musicality. Front Hum Neurosci 2020;14:350. DOI: 10.3389/fnhum.2020.00350.
67. Scatliffe N, Casavant S, Vittner D, et al. Oxytocin and early parent-infant interactions: A systematic review. Int J Nurs Sci 2019;6(4): 445–453. DOI: 10.1016/j.ijnss.2019.09.009.
68. Morris AR, Turner A, Gilbertson CH, et al. Physical touch during father-infant interactions is associated with paternal oxytocin levels. Infant Behav Dev 2021;64:101613. DOI: 10.1016/j.infbeh.2021.101613.
69. Pedersen CA, Caldwell JD, Walker C, et al. Oxytocin activates the postpartum onset of rat maternal behavior in the ventral tegmental and medial preoptic areas. Behav Neurosci 1994;108(6):1163–1171. DOI: 10.1037//0735-7044.108.6.1163.
70. Pedersen CA. Oxytocin control of maternal behavior. Regulation by sex steroids and offspring stimuli. Ann N Y Acad Sci 1997;807:126–145. DOI: 10.1111/j.1749-6632.1997.tb51916.x.
71. Takano Y, Umezawa M, Kubota N, et al. Effects of music exposure during pregnancy on maternal behavior in mother rats. Heliyon 2022;8(8):e10029. DOI: 10.1016/j.heliyon.2022.e10029.
72. Champagne F, Diorio J, Sharma S, et al. Naturally occurring variations in maternal behavior in the rat are associated with differences in estrogen-inducible central oxytocin receptors. Proc Natl Acad Sci USA 2001;98(22):12736–12741. DOI: 10.1073/pnas.221224598.
73. Kim P, Strathearn L, Swain JE. The maternal brain and its plasticity in humans. Horm Behav 2016;77:113–123. DOI: 10.1016/j.yhbeh.2015.08.001.
74. Bosch OJ, Neumann ID. Both oxytocin and vasopressin are mediators of maternal care and aggression in rodents: From central release to sites of action. Horm Behav 2012;61(3):293–303. DOI: 10.1016/j.yhbeh.2011.11.002.
75. Pedersen CA, Vadlamudi S, Boccia ML, et al. Variations in maternal behavior in C57BL/6J mice: Behavioral comparisons between adult offspring of high and low pup-licking mothers. Front Psychiatry 2011;2:42. DOI: 10.3389/fpsyt.2011.00042.
76. Priebe K, Romeo RD, Francis DD, et al. Maternal influences on adult stress and anxiety-like behavior in C57BL/6J and BALB/cJ mice: A cross-fostering study. Dev Psychobiol 2005;47(4):398–407. DOI: 10.1002/dev.20098.
77. Francis DD, Champagne FC, Meaney MJ. Variations in maternal behaviour are associated with differences in oxytocin receptor levels in the rat. J Neuroendocrinol 2000;12(12):1145–1148. DOI: 10.1046/j.1365-2826.2000.00599.x.
78. Rich ME, deCardenas EJ, Lee HJ, et al. Impairments in the initiation of maternal behavior in oxytocin receptor knockout mice. PLoS One 2014;9(6):e98839. DOI: 10.1371/journal.pone.0098839.
79. Pino O, Di Pietro S, Poli D. Effect of musical stimulation on placental programming and neurodevelopment outcome of preterm infants: A systematic review. Int J Environ Res Public Health 2023;20(3):2718. DOI: 10.3390/ijerph20032718.
80. Zuccarello D, Sorrentino U, Brasson V, et al. Epigenetics of pregnancy: Looking beyond the DNA code. J Assist Reprod Genet 2022;39(4): 801–816. DOI: 10.1007/s10815-022-02451-x.
81. King AJ, Teki S, Willmore BDB. Recent advances in understanding the auditory cortex. F1000Res. 2018;7:F100 Faculty Rev-1555. DOI: 10.12688/f1000research.15580.1.
82. King AJ, Schnupp JW. The auditory cortex. Curr Biol 2007;17(7): R236–R239. DOI: 10.1016/j.cub.2007.01.046.
83. Lopez Ramon YCC. Antenatal study of the Heschl's gyrus: The first step to understanding prenatal learning. Med Hypotheses 2019;130:109290. DOI: 10.1016/j.mehy.2019.109290.
84. Bleibel M, El Cheikh A, Sadier NS, et al. The effect of music therapy on cognitive functions in patients with Alzheimer's disease: A systematic review of randomized controlled trials. Alzheimers Res Ther 2023;15(1):65. DOI: 10.1186/s13195-023-01214-9.
85. Schlaug G. Part VI introduction: Listening to and making music facilitates brain recovery processes. Ann N Y Acad Sci 2009;1169: 372–373. DOI: 10.1111/j.1749-6632.2009.04869.x.
86. Rauscher FH, Shaw GL, Ky KN. Music and spatial task performance. Nature 1993;365(6447):611. DOI: 10.1038/365611a0.
87. Thompson WF, Schellenberg EG, Husain G. Arousal, mood, and the Mozart effect. Psychol Sci 2001;12(3):248–251. DOI: 10.1111/1467-9280.00345.
88. Fukui H, Toyoshima K. Music facilitate the neurogenesis, regeneration and repair of neurons. Med Hypotheses 2008;71(5):765–769. DOI: 10.1016/j.mehy.2008.06.019.
89. Machin AJ, Dunbar R. The brain opioid theory of social attachment: A review of the evidence. Behaviour 2011;148(9–10):985–1025. DOI: 10.1163/000579511X596624.
90. Corbijn van Willenswaard K, Lynn F, McNeill J, et al. Music interventions to reduce stress and anxiety in pregnancy: A systematic review and meta-analysis. BMC Psychiatry 2017;17(1):271. DOI: 10.1186/s12888-017-1432-x.
91. Sanfilippo KRM, Stewart L, Glover V. How music may support perinatal mental health: An overview. Arch Womens Ment Health 2021;24(5):831–839. DOI: 10.1007/s00737-021-01178-5.
92. Garcia Gonzalez J, Ventura Miranda MI, Requena Mullor M, et al. Effects of prenatal music stimulation on state/trait anxiety in full-term pregnancy and its influence on childbirth: A randomized controlled trial. J Matern Fetal Neonatal Med 2018;31(8):1058–1065. DOI: 10.1080/14767058.2017.1306511.
93. Lobmaier SM, Muller A, Zelgert C, et al. Fetal heart rate variability responsiveness to maternal stress, non-invasively detected from maternal transabdominal ECG. Arch Gynecol Obstet 2020;301(2): 405–414. DOI: 10.1007/s00404-019-05390-8.
94. Shimada BMO, Santos M, Cabral MA, et al. Interventions among pregnant women in the field of music therapy: A systematic review. Rev Bras Ginecol Obstet 2021;43(5):403–413. DOI: 10.1055/s-0041-1731924.
95. Maul J, Behnam S, Wimberger P, et al. Systematic review on music interventions during pregnancy in favor of the well-being of mothers and eventually their offspring. Am J Obstet Gynecol MFM 2024;6(8):101400. DOI: 10.1016/j.ajogmf.2024.101400.
96. Koelsch S. Toward a neural basis of music perception – A review and updated model. Front Psychol 2011;2:110. DOI: 10.3389/fpsyg.2011.00110.
97. Hepper PG, Shahidullah BS. Development of fetal hearing. Arch Dis Child Fetal Neonatal Ed 1994;71(2):F81–F817. DOI: 10.1136/fn.71.2.f81.
98. Partanen E, Kujala T, Tervaniemi M, et al. Prenatal music exposure induces long-term neural effects. PLoS One 2013;8(10):e78946. DOI: 10.1371/journal.pone.0078946.
99. James DK, Spencer CJ, Stepsis BW. Fetal learning: A prospective randomized controlled study. Ultrasound Obstet Gynecol 2002;20(5):431–438. DOI: 10.1046/j.1469-0705.2002.00845.x.
100. Granier-Deferre C, Bassereau S, Ribeiro A, et al. A melodic contour repeatedly experienced by human near-term fetuses elicits a profound cardiac reaction one month after birth. PLoS One 2011;6(2):e17304. DOI: 10.1371/journal.pone.0017304.
101. Brillo E, Tosto V, Ceccagnoli A, et al. The effect of prenatal exposure to music on fetal movements and fetal heart rate: A pilot study.

J Matern Fetal Neonatal Med 2021;34(14):2274–2282. DOI: 10.1080/14767058.2019.1663817.

102. Catalgol S, Ceber Turfan E. The effects of music therapy applied to pregnant women on maternal, fetal, and neonatal results: A randomized controlled study. Health Care Women Int 2022;43(5):448–464. DOI: 10.1080/07399332.2021.1944150.

103. Soylu N, Bulbul T, Muderris, II. The effect of music on fetal well-being and anxiety levels and vital signs of pregnant women during non-stress test: Turkey sample. Health Care Women Int 2022;43(5):499–517. DOI: 10.1080/07399332.2021.1973010.

104. Oh MO, Kim YJ, Baek CH, et al. [Effect of music intervention on maternal anxiety and fetal heart rate pattern during non-stress test]. J Korean Acad Nurs 2016;46(3):315–326. DOI: 10.4040/jkan.2016.46.3.315.

105. Estrella-Juarez F, Requena-Mullor M, Garcia-Gonzalez J, et al. Effect of virtual reality and music therapy on the physiologic parameters of pregnant women and fetuses and on anxiety levels: A randomized controlled trial. J Midwifery Womens Health 2023;68(1):35–43. DOI: 10.1111/jmwh.13413.

106. Lang A, Ott P, Del Giudice R, et al. Memory traces formed in utero-newborns' autonomic and neuronal responses to prenatal stimuli and the maternal voice. Brain Sci 2020;10(11). DOI: 10.3390/brainsci10110837.

107. Haslbeck FB, Mueller K, Karen T, et al. Musical and vocal interventions to improve neurodevelopmental outcomes for preterm infants. Cochrane Database Syst Rev 2023;9(9):CD013472. DOI: 10.1002/14651858.CD013472.pub2.

108. Calabro JL. Music therapy for infants with neonatal abstinence syndrome. Music Med 2017;9(1):37–44. DOI: 10.47513/mmd.v9i1.519.

109. Caparros-Gonzalez RA, de la Torre-Luque A, Diaz-Piedra C, et al. Listening to relaxing music improves physiological responses in premature infants: A randomized controlled trial. Adv Neonatal Care 2018;18(1):58–69. DOI: 10.1097/ANC.0000000000000448.

110. Cevasco AM. The effects of mothers' singing on full-term and preterm infants and maternal emotional responses. J Music Ther 2008;45(3):273–306. DOI: 10.1093/jmt/45.3.273.

111. Epstein S, Bauer S, Levkovitz Stern O, et al. Preterm infants with severe brain injury demonstrate unstable physiological responses during maternal singing with music therapy: A randomized controlled study. Eur J Pediatr 2021;180(5):1403–1412. DOI: 10.1007/s00431-020-03890-3.

112. Ettenberger M, Odell-Miller H, Cárdenas CR, et al. Music therapy with premature infants and their caregivers in Colombia – A mixed methods pilot study including a randomized trial. 2014;14(2). DOI: 10.15845/voices.v14i2.756.

113. Farhat A, Amiri R, Karbandi S, et al. The effect of listening to lullaby music on physiologic response and weight gain of premature infants. J Neonatal Perinatal Med 2010;3(2):103–107. DOI: 10.3233/NPM-2010-0101.

114. Haslbeck FB, Bucher HU, Bassler D, et al. Creative music therapy and neurodevelopmental outcomes in pre-term infants at 2 years: A randomized controlled pilot trial. Front Pediatr 2021;9:660393. DOI: 10.3389/fped.2021.660393.

115. Jabraeili M, Sabet T, Mustafa Gharebaghi M, et al. The effect of recorded mum's lullaby and brahm's lullaby on oxygen saturation in preterm infants: A randomized double-blind clinical trial. J Caring Sci 2016;5(1):85–93. DOI: 10.15171/jcs.2016.009.

116. Johnston CC, Filion F, Nuyt AM. Recorded maternal voice for preterm neonates undergoing heel lance. Adv Neonatal Care 2007;7(5): 258–266. DOI: 10.1097/01.ANC.0000296634.26669.13.

117. Kehl SM, La Marca-Ghaemmaghami P, Haller M, et al. Creative music therapy with premature infants and their parents: A mixed-method pilot study on parents' anxiety, stress and depressive symptoms and parent-infant attachment. Int J Environ Res Public Health 2020;18(1):265. DOI: 10.3390/ijerph18010265.

118. Kraft KE, Jaschke AC, Ravensbergen AG, et al. Maternal anxiety, infant stress, and the role of live-performed music therapy during NICU stay in the netherlands. Int J Environ Res Public Health 2021;18(13):7077. DOI: 10.3390/ijerph18137077.

119. Kucuk Alemdar D, Inal S. The effect of individualized developmental care practices in preterm infants. Complement Med Res 2020;27(2):97–104. DOI: 10.1159/000504357.

120. Lafferty MA, Mackley A, Green P, et al. Can mozart improve weight gain and development of feeding skills in premature infants? A Randomized Trial. Am J Perinatol 2023;40(7):793–798. DOI: 10.1055/s-0041-1731279.

121. Lejeune F, Lordier L, Pittet MP, et al. Effects of an early postnatal music intervention on cognitive and emotional development in preterm children at 12 and 24 months: Preliminary findings. Front Psychol 2019;10:494. DOI: 10.3389/fpsyg.2019.00494.

122. Liao J, Liu G, Xie N, et al. Mothers' voices and white noise on premature infants' physiological reactions in a neonatal intensive care unit: A multi-arm randomized controlled trial. Int J Nurs Stud 2021;119:103934. DOI: 10.1016/j.ijnurstu.2021.103934.

123. Loewy J, Stewart K, Dassler AM, et al. The effects of music therapy on vital signs, feeding, and sleep in premature infants. Pediatrics 2013;131(5):902–918. DOI: 10.1542/peds.2012-1367.

124. Menke BM, Hass J, Diener C, et al. Family-centered music therapy-empowering premature infants and their primary caregivers through music: Results of a pilot study. PLoS One 2021;16(5):e0250071. DOI: 10.1371/journal.pone.0250071.

125. Nakhwa PK, Malawade M, Shrikhande DY, et al. Efficacy of music therapy in improvement of neuromotor development in preterm infants. Romanian J Phys Ther 2017;23(39):5–11. Available from: https://revrokineto.uoradea.ro/23_40/1.rovrekineto_23_40_Priyanka.pdf.

126. Namjoo R, Mehdipour-Rabori R, Bagherian B, et al. Comparing the effectiveness of mother's live lullaby and recorded lullaby on physiological responses and sleep of preterm infants: A clinical trial study. J Complement Integr Med 2021;19(1):121–129. DOI: 10.1515/jcim-2020-0507.

127. Portugal CM, Sá LO, Guimarães MH. Cardiorespiratory effects of maternal sounds in infants born between 26 and 33 weeks of gestation. Revista de Enfermagem Referencia 2017;4(12):55–63. DOI: 10.12707/RIV16075.

128. Tandoi F, Francescato G, Pagani A, et al. "The Original Sound": A new non-pharmacological approach to the postnatal stress management of preterm infants. J Matern Fetal Neonatal Med 2015;28(16): 1934–1938. DOI: 10.3109/14767058.2014.973392.

129. Vastani MA, Zahedpasha Y, Amiri SR, et al. The effect of experience on recognition of mother's voice in preterm infants. Nurs Midwifery Stud 2017;6(1):7. DOI: 10.17795/nmsjournal40964.

130. White-Traut RC, Nelson MN. Maternally administered tactile, auditory, visual, and vestibular stimulation: Relationship to later interactions between mothers and premature infants. Res Nurs Health 1988;11(1):31–39. DOI: 10.1002/nur.4770110106.

131. Wirth L, Dorn F, Wege M, et al. Effects of standardized acoustic stimulation in premature infants: A randomized controlled trial. J Perinatol 2016;36(6):486–492. DOI: 10.1038/jp.2016.1.

132. Yu WC, Chiang MC, Lin KC, et al. Effects of maternal voice on pain and mother-Infant bonding in premature infants in Taiwan: A randomized controlled trial. J Pediatr Nurs 2022;63:e136–e142. DOI: 10.1016/j.pedn.2021.09.022.

133. Alipour Z, Eskandari N, Ahmari Tehran H, et al. Effects of music on physiological and behavioral responses of premature infants: A randomized controlled trial. Complement Ther Clin Pract 2013;19(3):128–132. DOI: 10.1016/j.ctcp.2013.02.007.

134. Amini E, Rafiei P, Zarei K, et al. Effect of lullaby and classical music on physiologic stability of hospitalized preterm infants: A randomized trial. J Neonatal Perinatal Med 2013;6(4):295–301. DOI: 10.3233/NPM-1371313.

135. Arnon S, Shapsa A, Forman L, et al. Live music is beneficial to preterm infants in the neonatal intensive care unit environment. Birth 2006;33(2):131–136. DOI: 10.1111/j.0730-7659.2006.00090.x.

136. Arnon S, Diamant C, Bauer S, et al. Maternal singing during kangaroo care led to autonomic stability in preterm infants and reduced

maternal anxiety. Acta Paediatr 2014;103(10):1039–1044. DOI: 10.1111/apa.12744.
137. Auto FM, Amancio OM, de Córdoba Lanza F. The effect of music on weight gain of preterm infants older than 32 weeks: A randomized clinical trial. Revista Paulista de Pediatria 2013;33(4):e293–e299. DOI: 10.1590/0103-058231369512.
138. Kurdahi Badr L, Demerjian T, Daaboul T, et al. Preterm infants exhibited less pain during a heel stick when they were played the same music their mothers listened to during pregnancy. Acta Paediatr 2017;106(3):438–445. DOI: 10.1111/apa.13666.
139. Barandouzi ZA, Keshavarz M, Montazeri A, et al. Comparison of the analgesic effect of oral sucrose and/or music in preterm neonates: A double-blind randomized clinical trial. Complement Ther Med 2020;48:102271. DOI: 10.1016/j.ctim.2019.102271.
140. Bellieni CV, Buonocore G, Nenci A, et al. Sensorial saturation: An effective analgesic tool for heel-prick in preterm infants: A prospective randomized trial. Biol Neonate 2001;80(1):15–8. DOI: 10.1159/000047113.
141. Bergomi P, Chieppi M, Maini A, et al. Nonpharmacological techniques to reduce pain in preterm infants who receive heel-lance procedure: A randomized controlled trial. Res Theory Nurs Pract 2014;28(4):335–348. DOI: 10.1891/1541-6577.28.4.335.
142. Cavaiuolo C, Casani A, Di Manso G, et al. Effect of Mozart music on heel prick pain in preterm infants: A pilot randomized controlled trial. J Pediatr Neonatal Indiv Med 2015;4(1):5. DOI: 10.7363/040109.
143. Cevasco AM, Grant RE. Effects of the pacifier activated lullaby on weight gain of premature infants. J Music Ther 2005;42(2):123–139. DOI: 10.1093/jmt/42.2.123.
144. Chirico G, Cabano R, Villa G, et al. Randomised study showed that recorded maternal voices reduced pain in preterm infants undergoing heel lance procedures in a neonatal intensive care unit. Acta Paediatr 2017;106(10):1564–1568. DOI: 10.1111/apa.13944.
145. Chorna OD, Hamm EL, Shrivastava H, et al. Feasibility of event-related potential (ERP) biomarker use to study effects of mother's voice exposure on speech sound differentiation of preterm infants. Dev Neuropsychol 2018;43(2):123–134. DOI: 10.1080/87565641.2018.1433671.
146. Corrigan MJ, Keeler JR, Miller HD, et al. Music therapy and retinopathy of prematurity screening: Using recorded maternal singing and heartbeat for post exam recovery. J Perinatol 2020;40(12):1780–1788. DOI: 10.1038/s41372-020-0719-9.
147. Corrigan M, Keeler J, Miller H, et al. Music therapy and family-integrated care in the NICU: Using heartbeat-music interventions to promote mother-infant bonding. Adv Neonatal Care 2022;22(5):E159–E168. DOI: 10.1097/ANC.0000000000000910.
148. Dalili H, Zaker Z, Keihanidoust Z, et al. Comparison of neuro-developmental status in preterm neonates with and without family based interventions. World J Adv Res Rev 2020;8(2):56–63. DOI: 10.30574/wjarr.2020.8.2.0357.
149. Dearn T, Shoemark H. The effect of maternal presence on premature infant response to recorded music. J Obstet Gynecol Neonatal Nurs 2014;43(3):341–350. DOI: 10.1111/1552-6909.12303.
150. Detmer MR, Evans K, Shina E, et al. Multimodal neurologic enhancement improves preterm infants' developmental outcomes: A longitudinal pilot study. Neonatal Netw 2020;39(1):16–23. DOI: 10.1891/0730-0832.39.1.16.
151. Doheny L, Hurwitz S, Insoft R, et al. Exposure to biological maternal sounds improves cardiorespiratory regulation in extremely preterm infants. J Matern Fetal Neonatal Med 2012;25(9):1591–1594. DOI: 10.3109/14767058.2011.648237.
152. Dora O, Buyuk ET. RETRACTED: Effect of white noise and lullabies on pain and vital signs in invasive interventions applied to premature babies. Pain Manag Nurs 2021;22(6):724–729. DOI: 10.1016/j.pmn.2021.05.005.
153. Edraki M, Beheshtipour N, Razavi SM, et al. Studying the effect of lullaby on some physiological factors. Pharmacophore 2017;8(6S):e-1173552. Available from: https://pharmacophorejournal.com/g26w59r.
154. Efendi D, Caswini N, Rustina Y, et al. Combination of mother therapeutic touch (MTT) and maternal voice stimulus (MVS) therapies stabilise sleep and physiological function in preterm infants receiving minor invasive procedures. J Neonat Nurs 2018;24(6):318–324. DOI: 10.1016/j.jnn.2018.08.001.
155. Eskandari N, Keshavars M, Ashayeri H, et al. Quran recitation: Short-term effects and related factors in preterm newborns. Res J Med Sci 2012;6(3):148–153. Available from: https://www.medwelljournals.com/abstract/?doi=rjmsci.2012.148.153.
156. Filippa M, Monaci MG, Spagnuolo C, et al. Maternal speech decreases pain scores and increases oxytocin levels in preterm infants during painful procedures. Sci Rep 2021;11(1):17301. DOI: 10.1038/s41598-021-96840-4.
157. Garunkstiene R, Buinauskiene J, Uloziene I, et al. Controlled trial of live versus recorded lullabies in preterm infants. Nordic J Music Ther 2014;23(1):71–88. DOI: 10.1080/08098131.2013.809783.
158. Holsti L, MacLean K, Oberlander T, et al. Calmer: A robot for managing acute pain effectively in preterm infants in the neonatal intensive care unit. Pain Rep 2019;4(2):e727. DOI: 10.1097/PR9.0000000000000727.
159. Johnston CC, Filion F, Campbell-Yeo M, et al. Enhanced kangaroo mother care for heel lance in preterm neonates: A crossover trial. J Perinatol 2009;29(1):51–56. DOI: 10.1038/jp.2008.113.
160. Kahraman A, Gumus M, Akar M, et al. The effects of auditory interventions on pain and comfort in premature newborns in the neonatal intensive care unit; a randomised controlled trial. Intensive Crit Care Nurs 2020;61:102904. DOI: 10.1016/j.iccn.2020.102904.
161. Kanagasabai PS, Mohan D, Lewis LE, et al. Effect of multisensory stimulation on neuromotor development in preterm infants. Indian J Pediatr 2013;80(6):460–464. DOI: 10.1007/s12098-012-0945-z.
162. Karadag OE, Kerimoglu Yildiz G, Akdogan R, et al. The effect of simulative heartbeat nest used in preterm new-borns on vital signs, pain, and comfort in Turkey: A randomized controlled study. J Pediatr Nurs 2022;62:e170–e177. DOI: 10.1016/j.pedn.2021.10.003.
163. Karimi A, Zabihi A, Zahed Pasha Y, et al. The effect of music on the anxiety of mothers of infants admitted to the neonatal intensive Care Unit. J Babol Uni Med Sci 2020;22(1):348–354. DOI: 10.22088/jbums.22.1.348.
164. Keith DR, Russell K, Weaver BS. The effects of music listening on inconsolable crying in premature infants. J Music Ther 2009;46(3):191–203. DOI: 10.1093/jmt/46.3.191.
165. Kucuk Alemdar D, Guducu Tufekc IF. Effects of maternal heart sounds on pain and comfort during aspiration in preterm infants. Jpn J Nurs Sci 2018;15(4):330–339. DOI: 10.1111/jjns.12202.
166. Majidipour N, Nirouzad F, Madmoli Y, et al. The effect of holy quran recitation on the physiological responses of premature infants during phlebotomy: A randomized clinical trial. Int J Pediatr 2018;6(7):7869–7881. DOI: 10.22038/ijp.2017.24203.2038.
167. Picciolini O, Porro M, Meazza A, et al. Early exposure to maternal voice: effects on preterm infants development. Early Hum Dev 2014;90(6):287–292. DOI: 10.1016/j.earlhumdev.2014.03.003.
168. Qolizadeh A, Myaneh ZT, Rashvand F. Investigating the effect of listening to the Holy Quran on the physiological responses of neonates admitted to neonatal intensive care units: A pilot study. Adv Integr Med 2019;6(4):159–162. DOI: 10.1016/j.aimed.2018.08.004.
169. Ramezani Z, Pasha YZ, Jafarian Amiri SR, et al. Comparison of the effectiveness of warm compress and music on the pain caused by heel blood sampling in neonates: a single-blind, prospective, randomized controlled trial. Crescent J Med Biol Sci 2020;7(1):138–139. Available from: https://www.cjmb.org/uploads/pdf/pdf_CJMB_359.pdf#:~:text=The%20primary%20outcomes%20showed%20that,group%20(P%20%3C%200.001).
170. Ranger A, Helmert E, Bott TS, et al. Physiological and emotional effects of pentatonic live music played for preterm neonates and their mothers in the Newborn Intensive Care Unit: A randomized controlled trial. Complement Ther Med 2018;41:240–246. DOI: 10.1016/j.ctim.2018.07.009.
171. Sarhangi F, Azarmnejad E, Javadi M, et al. The effect of the mother's heartbeat sound on physiological parameters and pain intensity after

blood sampling in neonates in the intensive care unit: A randomized controlled clinical trial. J Neonatal Nurs 2021;27(2):123–128. DOI: 10.1016/j.jnn.2020.07.006.
172. Schlez A, Litmanovitz I, Bauer S, et al. Combining kangaroo care and live harp music therapy in the neonatal intensive care unit setting. Isr Med Assoc J 2011;13(6):354–358. PMID: 21809733.
173. Shabani F, Nayeri ND, Karimi R, et al. Effects of music therapy on pain responses induced by blood sampling in premature infants: A randomized cross-over trial. Iran J Nurs Midwifery Res 2016;21(4): 391–396. DOI: 10.4103/1735-9066.185581.
174. Shah SR, Kadage S, Sinn J. Trial of music, sucrose, and combination therapy for pain relief during heel prick procedures in neonates. J Pediatr 2017;190:153–158.e2. DOI: 10.1016/j.jpeds.2017.08.003.
175. Shukla VV, Bansal S, Nimbalkar A, et al. Pain control interventions in preterm neonates: A randomized controlled trial. Indian Pediatr 2018;55(4):292–296. PMID: 29428919.
176. Standley JM, Moore RS. Therapeutic effects of music and mother's voice on premature infants. Pediatr Nurs 1995;21(6):509–512, 574. PMID: 8700604.
177. Standley JM. The effect of contingent music to increase non-nutritive sucking of premature infants. Pediatr Nurs 2000;26(5):493–495, 498–499. PMID: 12026338.
178. Standley JM. The effect of music-reinforced nonnutritive sucking on feeding rate of premature infants. J Pediatr Nurs 2003;18(3):169–173. DOI: 10.1053/jpdn.2003.34.
179. Standley JM, Cassidy J, Grant R, et al. The effect of music reinforcement for non-nutritive sucking on nipple feeding of premature infants. Pediatr Nurs 2010;36(3):138–145. PMID: 20687305.
180. Stokes A, Agthe AG, El Metwally D. Music exposure and maturation of late preterm sleep-wake cycles: A randomised crossover trial. Acta Paediatr 2018;107(4):582–586. DOI: 10.1111/apa.14079.
181. Tang L, Wang H, Liu Q, et al. Effect of music intervention on pain responses in premature infants undergoing placement procedures of peripherally inserted central venous catheter: A randomized controlled trial. Eur J Integr Med 2018;19(1):105–109. DOI: 10.1016/j.eujim.2018.03.006.
182. Tekgunduz KS, Polat S, Gurol A, et al. Oral glucose and listening to lullaby to decrease pain in preterm infants supported with NCPAP: A randomized controlled trial. Pain Manag Nurs 2019;20(1):54–61. DOI: 10.1016/j.pmn.2018.04.008.
183. Uematsu H, Sobue I. Effect of music (Brahms lullaby) and non-nutritive sucking on heel lance in preterm infants: A randomized controlled crossover trial. Paediatr Child Health 2019;24(1):e33–e39. DOI: 10.1093/pch/pxy072.
184. Polkki T, Korhonen A. The effectiveness of music on pain among preterm infants in the neonatal intensive care unit: A systematic review. JBI Libr Syst Rev 2012;10(58):4600–4609. DOI: 10.11124/jbisrir-2012-428.
185. Vahdati M, Mohammadizadeh M, Talakoub S. Effect of kangaroo care combined with music on the mother-premature neonate attachment: A randomized controlled trial. Iran J Nurs Midwifery Res 2017;22(5):403–407. DOI: 10.4103/ijnmr.IJNMR_50_16.
186. Walworth D, Standley JM, Robertson A, et al. Effects of neurodevelopmental stimulation on premature infants in neonatal intensive care: Randomized controlled trial. J Neonat Nurs 2012;18(6):210–216. DOI: 10.1016/j.jnn.2012.01.001.
187. White-Traut RC, Nelson MN, Silvestri JM, et al. Developmental patterns of physiological response to a multisensory intervention in extremely premature and high-risk infants. J Obstet Gynecol Neonatal Nurs 2004;33(2):266–275. DOI: 10.1177/0884217504263289.
188. Wu HP, Yang L, Lan HY, et al. Effects of combined use of mother's breast milk, heartbeat sounds, and non-nutritive sucking on preterm infants' behavioral stress during venipuncture: A randomized controlled trial. J Nurs Scholarsh 2020;52(5):467–475. DOI: 10.1111/jnu.12571.
189. Yildiz A, Arikan D. The effects of giving pacifiers to premature infants and making them listen to lullabies on their transition period for total oral feeding and sucking success. J Clin Nurs 2012;21(5–6):644–656. DOI: 10.1111/j.1365-2702.2010.03634.x.
190. Yilmaz G, Kucuk Alemdar D. The effect of supportive nursing interventions on reducing stress levels of mothers of infants in the neonatal intensive care unit: A randomized controlled trial. Clin Nurs Res 2022;31(5):941–951. DOI: 10.1177/10547738211047359.
191. Zeraati H, Nasimi F, Rezaeian A, et al. Effect of multi-sensory stimulation on neuromuscular development of premature infants: A randomized clinical trial. Iran J Child Neurol 2018;12(3):32–39. PMID: 30026767.
192. Erkun Dolker H, Basar F. The effect of music on the non-stress test and maternal anxiety. Complement Ther Clin Pract 2019;35:259–264. DOI: 10.1016/j.ctcp.2019.03.007.
193. Gebuza G, Zaleska M, Kazmierczak M, et al. The effect of music on the cardiac activity of a fetus in a cardiotocographic examination. Adv Clin Exp Med 2018;27(5):615–621. DOI: 10.17219/acem/68693.
194. Gebuza G, Dombrowska A, Kazmierczak M, et al. The effect of music therapy on the cardiac activity parameters of a fetus in a cardiotocographic examination. J Matern Fetal Neonatal Med 2017;30(20):2440–2445. DOI: 10.1080/14767058.2016.1253056.
195. Poreba A, Dudkiewicz D, Drygalski M. [The influence of the sounds of music on chosen cardiotocographic parameters in mature pregnancies]. Ginekol Pol 2000;71(8):915–920. PMID: 11082948.
196. Lee L, Chang YH, Liang WJ, et al. The effect of music intervention on fetal education via doppler fetal monitor. Children (Basel) 2022;9(6):918. DOI: 10.3390/children9060918.
197. SAMHSA. Clinical guidance for treating pregnant and parenting women and opioid use disorder and their infants. Rockville, Maryland, USA: Substance Abuse and Mental Health Services Administration; 2018 Available from: https://store.samhsa.gov/product/Clinical-Guidance-for-Treating-Pregnant-and-Parenting-Women-With-Opioid-Use-Disorder-and-Their-Infants/SMA18-5054.
198. Committee OG. Committee Opinion No. 711: Opioid use and opioid use disorder in pregnancy. Obstet Gynecol 2017;130(2):e81–e94. DOI: 10.1097/AOG.0000000000002235.
199. Anbalagan S, Falkowitz DM, Mendez MD. Neonatal abstinence syndrome. StatPearls. Treasure Island (FL), 2024. Available from: https://www.ncbi.nlm.nih.gov/books/NBK551498/.
200. Hirai AH, Ko JY, Owens PL, et al. Neonatal abstinence syndrome and maternal opioid-related diagnoses in the US, 2010–2017. JAMA 2021;325(2):146–155. DOI: 10.1001/jama.2020.24991.
201. Forray A. Substance use during pregnancy. F1000Res 2016;5:F1000 Faculty Rev-887. DOI: 10.12688/f1000research.7645.1.