

# Does Noise Exposure during Pregnancy Affect Neonatal Hearing Screening Results?

Selis Gülseven Güven<sup>1</sup>, Memduha Taş<sup>2</sup>, Erdoğan Bulut<sup>2</sup>, Burcu Tokuç<sup>3</sup>, Cem Uzun<sup>1</sup>, Ahmet Rifat Karasalihoğlu<sup>1</sup>

<sup>1</sup>Department of Otorhinolaryngology, Head and Neck Surgery, Trakya University Faculty of Medicine, Edirne, Turkey, <sup>2</sup>Department of Audiology, Trakya University Faculty of Health Sciences, Edirne, Turkey, <sup>3</sup>Department of Public Health, Trakya University Faculty of Medicine, Edirne, Turkey

## Abstract

**Objective:** The aim is to investigate whether noise is effective on hearing screening tests of neonates born to mothers exposed to noise during pregnancy. **Material and Method:** Screening results of 2653 infants from the period of January 2013–May 2017 were evaluated. Transient Evoked Otoacoustic Emissions (TEOAE) and Auditory Brainstem Response (ABR) were used. Infants of 65 mothers exposed to noise ( $L_{Aeq}$  80–85 dBA/8 hours/day) during pregnancy (Week  $\pm$  SD;  $32.58 \pm 2.71$ ) comprised the study group while the control group consisted of infants of 2588 mothers without noise exposure. **Results:** Among the 65 infants, 23 (35.4%) passed screening at the first emission test (OAE1); 34 (52.3%) at the second emission test (OAE2); 7 (10.8%) at the ABR stage, 1 (1.5%) infant was referred to a tertiary center. In the control group, 458 (17.7%) infants passed at OAE1; 1822 (70.4%) at OAE2; 289 (11.2%) at ABR stages, 19 (0.7%) infants were referred to a tertiary center. The rate of infants that passed screening at OAE1 in the study group was high ( $P = 0.00001$ ). Sixty-four (98.46%) infants in the study group and 2569 (99.26%) infants in the control group passed the tests. The difference between the two groups was not significant, indicating that exposure to noise during pregnancy had no unfavorable effects on auditory functions ( $P = 0.392$ ). **Conclusion:** Unfavorable effect of noise exposure during pregnancy was not observed on auditory functions of the infants. The higher rate of infants that passed the screening test at OAE1 stage in the study group raised the question, “Does the exposure of the noise at exposure action levels (80–85 dB A) during pregnancy contribute to auditory maturation of fetus?”

**Keywords:** Hearing, neonate, neonatal screening, occupational noise, otoacoustic emissions, pregnancy

## INTRODUCTION

The causal relationship between exposure to intense noise and hearing loss has been known for centuries.<sup>[1]</sup> Noise has direct hazardous effects on the ear and harms an organism by creating stress in humans.<sup>[2]</sup> Long-term and high-intensity exposure to noise causes transient changes in the hearing threshold of a normal ear and returns to normal threshold after a certain amount of time. However, permanent hearing loss may occur as a result of exposure to high-level noise without ear protection for a prolonged duration. Industrial noise is the most well-known type of noise that results in permanent hearing loss. In chronic noise trauma, the outer hair cells and their supporting elements are the first to experience damage, which leads to cochlear-type sensorineural hearing loss. Destruction of the inner hair cells and the organ of Corti subsequently occurs. Physiological tolerance limit of sensory cells in the cochlea has been defined as continuous exposure to 85–90 dB noise for 8 hours.

Exceeding this limit results in noise-induced hearing loss.<sup>[3]</sup> In the field of public health and occupational medicine, several studies have been conducted concerning worker health such as studies on factory noise or noise that affects customers and employees in entertainment centers. Various investigators have also demonstrated that occupational noise exposure may cause hearing impairment in adults.<sup>[4]</sup> Hearing loss has been proven in people exposed to intense noise; however, the effects of

**Address for correspondence:** Assistant Professor Selis Gülseven Güven, MD, Department of Otorhinolaryngology, Head and Neck Surgery, Trakya University Faculty of Medicine, Edirne, 22030, Turkey. E-mail: sgueven1@hotmail.com

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such exposure on the hearing of an unborn child are not fully understood.<sup>5</sup>

Few studies in the literature have evaluated the effect of in utero exposure to occupational noise on an infant's auditory function. However, research indicates that environmental sounds have direct effects on the human fetus.<sup>[6]</sup> Some fetuses at gestational week 23 and all healthy fetuses at week 28 are capable of responding to noise impulses. During the intrauterine period, the sound of the maternal heartbeat, respiratory sounds, and sounds of organs in the body are evident in the acoustic environment. Under normal circumstances, background noise is 28 dB or higher and maybe as high as 84 dB when the mother is singing. The noise that may reach the fetus may be more audible than the background noise and high-frequency sounds are absorbed by maternal tissues.<sup>[7]</sup> Studies have reported that the fluid-filled middle ear provides protection for the fetus against noise and improves the symmetry of the cochlear structure by reducing the effect of direct bone transmission.<sup>[8,9]</sup> During pregnancy, sound is initially transmitted from the air, through the abdominal wall, through the uterus, and finally to the amniotic fluid and the head of the fetus. Noise stimulates the inner ear through soft tissue transmission. The maturing cochlea in particular is more sensitive to ototraumatic factors than is the cochlea of adults; therefore, noise may affect the hearing of a fetus by damaging internal and external hair cells in the cochlea.

Experimental studies in animals and in humans have demonstrated that the attenuation of noise along the abdominal wall and the uterine passage is strongly associated with frequency. A fetus is well protected against high-frequency noise; however, there is less protection against low-frequency noise because it may be less attenuated or may be amplified along the abdominal wall and passage through the amniotic fluid.<sup>[5,10,11]</sup> In the current era, owing to women's increased participation in business life, they may be in noisy environments during their pregnancy that are harmful for hearing. Considering the aforementioned hazards of noise, the present study investigated the potential effect of noise exposure on neonatal hearing screening test results. This effect warrants evaluation because it may be a risk factor in neonatal hearing screening programs.

## MATERIALS AND METHODS

### Participants

This study was a cross-sectional study conducted using the results of neonatal hearing screening tests administered from January 2013 to May 2017. Hearing screening test results of 2653 infants were evaluated. They did not have any identified risk factors for hearing loss and did not meet other exclusion criteria defined for this study (described later in "Exclusion Criteria"). Permission and ethics committee approval to conduct this study were obtained from the relevant

institutions and organizations. The need for patient approval was waived by the ethics review board.

Neonatal hearing screening tests were administered by properly trained individuals at the hospital's neonatal hearing screening unit in a quiet environment. During the test, care was taken to ensure that the infant was silent and stationary. The infant was often laid on the lap of the mother or on a stretcher. Adequate cleaning of the external ear canals of the infants was ensured, while considering accumulations associated with vernix caseosa or amniotic fluid. Test measurements of the diameter of the external ear canal were obtained by using the most appropriate probe. The Madsen AccuScreen screener (Otometrics, Taastrup, Denmark) was used for the transient-evoked otoacoustic emission and auditory brainstem response (ABR) tests.

### Screening protocol

The screening protocol implemented at the time of data collection for the study was, as follows: the initial emission test (OAE1) was administered within the infants' first few days of life; infants who failed this test were invited 15 days later to undergo a second emission test (OAE2); and if they failed again, they were invited 15–20 days later to undergo the ABR test. Infants who failed this third test were referred to a tertiary healthcare institution to undergo further hearing tests. Infants born to mothers who had vaginal delivery at the hospital were directed to the neonatal hearing screening unit for testing immediately before being discharged after the completion of the first 24 hours of life. Infants born to mothers who had undergone caesarean section were directed to the hearing test immediately before being discharged after the completion of the first 48 hours of life. When the time of discharge from the hospital coincided on a weekend, the screening was scheduled for the subsequent week day. In this way, the earliest time of OAE1 was a minimum of 24 hours and maximum 96 hours from the time of birth.

### Exclusion criteria

The exclusion criteria were as follows:

- (1) The infant had any of the risk factors for hearing loss, as defined in 1994 by American Academy of Pediatrics and Joint Committee on Infant Hearing: (1) exposure to the following infections during pregnancy: toxoplasmosis, other (e.g., syphilis, varicella-zoster, parvovirus B19), rubella, cytomegalovirus, and herpes [TORCH]; (2) a family history of childhood sensorineural hearing loss; (3) head and face anomalies involving the external ear canal and auricle; (4) born prematurely with a birth weight <1500 grams; (5) hyperbilirubinemia that required an exchange transfusion; (6) exposure to ototoxic drugs (e.g., aminoglycosides administered for more than one course, and concomitant exposure to loop diuretics); (7) bacterial meningitis; (8) an Apgar score of 0 to 4 at 1

minute or 0 to 6 at 5 minutes; (9) mechanical ventilation for >5 days; and (10) any syndrome that is accompanied by sensorineural or conductive hearing loss.

- (2) The infant's birth occurred at a center other than the hospital where the study was planned.
- (3) The infant was admitted to postnatal intensive care, with or without mechanical ventilation.
- (4) The infant's delivery occurred outside the range of 37–42 weeks of gestation.
- (5) The infant had another identified congenital health problem.

A total of 10,575 neonates were screened during the aforementioned period. During the review of neonatal hearing screening files, infants meeting any of the five exclusion criteria were excluded from the study. Medical history concerning the pregnancy period and noise exposure was subsequently obtained from the mothers. Neonates exposed to noise were identified, based on the answers to the following queries:

- (1) Was the pregnancy period a healthy one?
- (2) Did the mother work at a workplace during her pregnancy?
- (3) If “yes” to query #2, was there was noise exposure at the workplace?
- (4) If “yes” to query #3, was personal protective equipment available and used at the workplace? [Personal protective equipment should be provided if the workplace noise level is  $\geq 80$  dBA, and should be used if the noise level is  $\geq 85$  dBA, per the labor law.]<sup>[12]</sup>
- (5) If “yes” to query #4, was the mother present in the same working environment during 8 hours of her daily shift? [The daily shift is 8 hours if the workplace noise level is  $\leq 85$  dBA with a maximum duration of 40 hours per week, and durations are shortened if the noise level is  $> 85$  dBA, per the labor law and the World Health Organization.]<sup>[12,13]</sup>
- (6) Which gestational week did the mother take her maternal leave?

Mothers who answered “yes” to questions 1–5 and took their maternal leave no earlier than 28 weeks of gestation (based on question 6) were considered as having been exposed to a harmful noise level (i.e., 80–85 dBA) during pregnancy, and the hearing screening results of infants born to these mothers were included in the study group. Accordingly, we determined that the mothers of the newborns in the study group were exposed to 80–85 dBA noise throughout an average of  $32.58 \pm 2.71$  weeks of gestation for 8 hours a day for 5 days a week. The control group consisted of the hearing screening results of infants born to mothers who answered “yes” to the first question (i.e., mothers who had a healthy pregnancy period but were not exposed to harmful noise levels during pregnancy, based on questions 2–5. Data were consequently obtained and evaluated for 2653 neonates (65 infants in the study group and 2588 in the control group).

## Statistical analysis

Data were analyzed by using the SPSS program, version 22.0 (IBM Corp., Armonk, NY, USA). This study was a cross-sectional trial. For the statistical evaluation, Student's *t*-test was employed if the hearing test screening measurement results had a normal distribution in the study group and the control group, whereas the Mann–Whitney *U* test was used for comparing data without a normal distribution. Data are presented as counts were compared using the Chi-square test. When the  $\alpha$  level of significance was accepted as 0.05, the power of the study was calculated as 0.798.

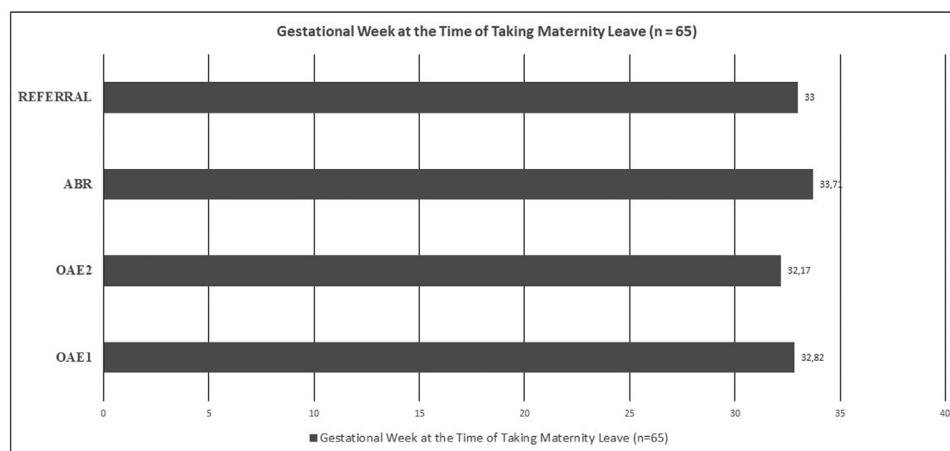
## RESULTS

In the study group, 30 (46%) infants were born by vaginal delivery and 35 (54%) infants were born by caesarean section. In the study group, 1541 (60%) infants were born by vaginal deliveries and 1047 (40%) infants were born by caesarean section. Thirty-two (49%) infants were girls and 33 (51%) infants were boys in the study group. The control group similarly consisted of 1279 (49%) girls and 1309 (51%) boys. For mothers working in a noisy workplace, the mean gestational week was  $32.58 \pm 2.73$  at the time of maternal leave (minimum, 28 weeks; maximum, 39 weeks).

Among the 65 infants in the study group, 23 (35.4%) infants passed the screening at OAE1; 34 (52.3%) infants, at OAE2; 7 (10.8%) infants, at the ABR stage; and 1 (1.5%) infant was referred to a tertiary diagnosis center because of suspected hearing loss. In the control group, 458 (17.7%) infants passed the screening at OAE1; 1822 (70.4%) infants passed at OAE2; and 289 (11.2%) infants passed at the ABR stage. Nineteen (0.7%) infants were referred to a tertiary diagnosis center because of suspected hearing loss (Table 1). The numbers for the OAE1, OAE2, and ABR stages indicated the corresponding number of infants for whom hearing screening was completed for both ears. Both ears of all infants at the OAE1 stage passed the screening. However, infants evaluated at the OAE2 and ABR stages had at least one ear that passed these stages and their screening was completed. The remaining 20 infants were planned for

**Table 1: Distribution of the number of infants that passed the hearing screening tests and infants referred for further investigation in the study and control groups**

Group	Stage of the hearing screening test			Referral <i>n</i> (%)
	OAE1	OAE2	ABR	
	<i>n</i> (%)	<i>n</i> (%)	<i>n</i> (%)	
Study group	23	34	7	1
( <i>n</i> = 65)	35.4%	52.3%	10.8%	1.5%
Control group	458	1822	289	19
( <i>n</i> = 2588)	17.7%	70.4%	11.2%	0.7%
Total	481	1856	296	20
( <i>n</i> = 2653)	18.1%	69.9%	11.2%	0.8%



**Figure 1:** Gestational week at the time of taking maternal leave among mothers exposed to noise versus the stage their infants passed the hearing screening. ABR, auditory brainstem response; OAE1, initial otoacoustic emission test; OAE2, second otoacoustic emission test

referral because some infants had screening failure in one ear and some infants had screening failure in both ears. Hearing screening tests revealed that 64 (98.46%) infants in the study group and 2569 (99.26%) infants in the control group passed the tests (i.e., had normal hearing). The difference between the two groups was statistically insignificant, which indicated that exposure to noise during pregnancy had no unfavorable effects on auditory functions of infants ( $P = 0.392$ ).

The results of the present study revealed a statistically significant increase in the rate of passing the OAE1 test in the study group (i.e., neonates exposed to noise), compared with the control group ( $P = 0.00001$ ). In the OAE2 and ABR tests, a high rate of passing the test was observed in the study group and in the control group; however, the difference was statistically insignificant ( $P = 0.553$ ).

When the hearing screening results of infants born to mothers exposed to noise were evaluated, based on the week of maternal leave, mothers of infants who passed the screening at OAE1 had taken their maternal leave on average at  $32.82 \pm 3.11$  weeks. By contrast, the time of maternal leave was  $32.17 \pm 2.43$  weeks for infants who passed at OAE2,  $33.71 \pm 2.98$  weeks for infants who passed the ABR test, and 33 weeks for infants referred because of suspected hearing loss. No statistically significant difference was found among mothers exposed to noise when the gestational week at the time of taking maternal leave [Figure 1] was evaluated, based on the stage of passing the neonatal hearing screening ( $P = 0.556$ ).

## DISCUSSION

The present study investigated the potential effect of noise exposure on neonatal hearing screening test results and demonstrated no unfavorable effect of noise exposure during pregnancy on the auditory function of infants. In the literature, few studies have evaluated the effect of in utero occupational noise on the infantile auditory function. To the best of our knowledge, the present study is the first to

demonstrate the effects of occupational noise on neonatal hearing screening tests.

In a study by Daniel and Laciak<sup>[14]</sup> on hearing functions among children whose mothers were exposed to occupational noise during pregnancy, 75 children who were 10–14 years old were evaluated. High-frequency hearing loss was detected in 35 children born to mothers who worked in the textile industry where the noise level can be as high as 100 dB. The authors suggested a relationship between hearing loss among these children and the occupational noise their mothers were exposed to during pregnancy. Lalande *et al.*<sup>[15]</sup> conducted a study in 131 children 4–7 years old and observed a greater prevalence of hearing loss among children whose mothers were exposed to noise louder than 85 dBA during their pregnancy period, compared with children whose mothers were exposed to 65–85 dBA. Furthermore, they showed a 3-fold higher risk of high-frequency hearing loss in children whose mothers had occupational noise exposure, and a significantly increased risk of hearing loss at 4000 Hz when low-frequency noise was the dominant component of the noise exposure. Both of the aforementioned studies received negative criticism because of methodological issues such as the lack of a control group.<sup>[5]</sup> In addition, the age range of the children included in these studies raise the question of whether factors related to hearing other than noise exposure could be involved in this process. These factors have been minimized in the present study because it was conducted using neonates.

In another study by Rocha *et al.*,<sup>[16]</sup> which was conducted using 80 infants 0–6 months old, the mothers of 35 infants had a history of occupational noise exposure (80–90 dB SPL for 8 hours for 5 days weekly) while pregnant (these infants constituted the study group), whereas the control group consisted of 45 infants whose mothers had not been exposed to noise during their pregnancy. Hearing in these infants was assessed by distortion product otoacoustic emissions (DPOAEs) and had findings similar to those of the present study: no hazardous effect was detected



with regard to hearing among infants born to mothers exposed to occupational noise during pregnancy. The noise exposure level of pregnant mothers in our study was 80–85 dB A for 8 hours for 5 days weekly. It was between lower and upper exposure action levels defined by the European Council directive<sup>[17]</sup>. Although the Occupational Safety and Health Administration (OSHA) action level for noise exposure is 85 dB (8-hour timeweighted average), the evidence suggests that noise exposure from 80 to 85 dB may contribute to hearing loss in individuals who are unusually susceptible. The risk of noise-induced hearing loss increases with long-term noise exposures above 80 dB and increases significantly as exposures rise above 85 dB<sup>[18]</sup>. In a study by Selander *et al.*,<sup>[11]</sup> occupational noise exposure during pregnancy was associated with auditory dysfunction in children. The study in question utilized the database information of all children born during 1986–2008 in Sweden. The authors reached this conclusion by matching the information extracted from healthcare data of years 2003–2008 for children diagnosed with sensorineural hearing loss, while excluding children with middle ear problems or conductive hearing loss, based on the *International Classification of Diseases, edition 10* (ICD-10), versus infants whose mothers had been exposed to occupational noise during pregnancy, based on birth data. Noise is not the sole cause of sensorineural hearing loss; therefore, it is misleading to associate all cases of sensorineural hearing loss in children with noise exposure.

In the present study, all potential causes that could lead to sensorineural hearing loss, apart from noise, were ruled out as much as possible. A more homogeneous study group and control group were formed, followed by an assessment using hearing screening tests initiated within the first days of life.

In their study, Ando and Hattori<sup>[19]</sup> reported that children born to mothers who were exposed to plane noise in locations close to airports during the first 5 months of pregnancy adapted to the same noisy environment more easily after birth, which suggested that they were more likely to adapt to environmental noise without potential hearing loss. It has been previously demonstrated that environmental acoustic enhancement may improve structural plasticity in the brain, thereby improving cognitive and behavioral functions.<sup>[20]</sup> To investigate whether such enhancement would restore the developmentally impaired behavioral and neuronal processing of sound frequency, investigators utilized rats exposed to noise during development for 4 weeks in an acoustically enhanced setting; they then compared rats exposed to noise during development with age-matched rats without noise exposure, and demonstrated a significantly higher threshold to distinguish sound frequency in the former group.<sup>[18]</sup> The behavioral and physiological effects that result from the enhancement were accompanied by improved cortical expression of brain-derived neurotrophic factor and certain *N*-methyl-D-aspartate and gamma-aminobutyric acid A (GABA<sub>A</sub>)

receptor subunits.<sup>[20]</sup> Webb *et al.*<sup>[21]</sup> have shown that the mother's voice and heart rate sounds lead to auditory plasticity in human brain before the completion of gestation, and thereby creates neural pathways for the development of hearing and language-related capabilities. Based on their findings, the authors suggested that exposure to maternal sounds provides neonates with the auditory fitness required for shaping the brain with regard to hearing and language development. In the present study, the fact that a greater proportion of infants exposed to noise in utero passed the hearing screening test at OAE1, compared with the control group, also suggests that a certain amount of noise exposure during pregnancy may contribute to the development of neonates with adequate auditory fitness.

With regard to animal studies concerning this matter, sheep are a good model for fetal human studies because the sound attenuation characteristics of the abdominal content in these animals are similar to those of humans. Sounds with an exogenous frequency lower than 0.2 kHz penetrate the uterus with a reduction less than 5 dB under sound pressure. In fact, even a mild increase in low-frequency sound pressure has been reported in humans and in sheep. Thus, intra-abdominal sound pressures may be greater than those in the extra-abdominal setting. Higher frequencies up to 4 kHz are attenuated by approximately 20 dB. In a study by Gerhardt and Abrams,<sup>[5]</sup> 90 dB signals at 0.125 kHz and 0.25 kHz were attenuated by 10–20 dB when they reached the inner ear of the fetus. However, a 90-dB signal at 0.5–2.0 kHz was reduced by 40–45 dB. For this frequency range, the fetus is isolated from sounds surrounding the mother because of the limited function of the bone chain; however, this attenuation does not occur for low-frequency sounds. The fact that low-frequency stimuli reaching the inner ear coincides with the development of the inner ear, which primarily starts from low-frequency sounds, is an interesting aspect.<sup>[5]</sup> Dunn *et al.*<sup>[22]</sup> exposed pregnant sheep to repetitive 130 dB SPL wide-band noise for 4 hours per day and 5 days a week for several weeks. There was no significant difference in the study group versus the control group when the investigators measured the ABR threshold in sheep during the first 30–40 days of life. In a study conducted by Cook *et al.*,<sup>[23]</sup> pregnant guinea pigs were exposed to previously recorded weaving loom noise at 115 dBA for 7.5 hours daily during the last trimester. The ABR measurements in the offspring revealed prolonged I-V wave latency. The authors concluded that in utero noise-related hearing loss may occur in mammals with near-complete prenatal auditory maturation process. Griffiths *et al.*<sup>[24]</sup> compared ABR measurements obtained from sheep fetuses in utero before and after noise exposure, and observed transient changes in the ABR thresholds and latencies immediately after exposure to noise. However, Pierson *et al.*<sup>[25]</sup> in their study exposed sheep fetuses to similar noise. They did not observe abrupt changes in ABR immediately after noise exposure, but they did observe significantly higher thresholds during the measurements

obtained at least 2 weeks after the fetuses were exposed to noise, compared with fetuses without a history of noise exposure. Huang *et al.*<sup>[1]</sup> exposed pregnant sheep to noise with low transition (<1 kHz) and high (>1 kHz) transition at 120 dB SPL for 16 hours. They then evaluated the ABR latency and thresholds against click and tone bursts before and after noise exposure. High transition noise exposure, except 1 kHz, showed highly limited effects on fetal ABR thresholds and I-V wave latencies among sheep. The exposure to the energy at lower frequencies may affect the fetal inner ear. Tone burst and click ABR thresholds at 2 kHz were not affected by this exposure. However, low transition noise exposure resulted in elevated fetal ABR thresholds generated with tone burst stimuli at 1.0 kHz and at 0.5 kHz. In addition, fetal ABR thresholds in response to wide-band clicks were elevated after low transition noise exposure. Response clicks were likely to originate from the basal region of the cochlea. However, exposure to continuous and repetitive long-term, low-frequency noise may cause low- and high-frequency hearing loss in postnatal animals. In conclusion, in their study in pregnant sheep, Huang *et al.*<sup>[1]</sup> confirmed that low-frequency sounds originating from the external surroundings of the sheep are transferred to the fetal inner ear, and lead to transient changes in the fetal ABR with a potentially hazardous effect that is even higher than that of high-frequency noise. Gerhardt *et al.*<sup>[26]</sup> demonstrated that intensive exogenous noise penetrates the uterus in pregnant sheep, and results in elevated ABR thresholds at 2–3 weeks after the noise exposure. The ABR thresholds against 0.5 kHz tone burst stimuli were affected to a greater extent than the ABR thresholds against click stimuli. In fetuses exposed to repetitive noise, hair cells in middle and apical turn of the cochlea were more damaged than those in the control group. No damage was detected in the basal turn of the cochlea.

Several studies have demonstrated that exposure to noise at levels not expected to cause harm in mature animals may cause severe high-frequency hearing loss and histological damage in the cochlea of young mammals. The increased sensitivity process corresponds to the last stage of morphological and functional development of the cochlea. The timing of this sensitivity process in human fetuses and neonates remains unknown. Further studies are warranted to address this question.<sup>[5]</sup> Autocyst embryonic stem cells can produce hair cell-like cells. These progenitor cells are predicted to react to loud sounds. Isolated adult mammalian cochlear outer hair cells respond with a change in length when they experience a sound stimulus, and each cell has a sharply tuned frequency response. If progenitor hair cells have the same capacity, the effect of noise during the earlier stages of pregnancy may also be possible.<sup>[11]</sup>

Morimoto *et al.*<sup>[27]</sup> investigated the effect of exposure to noise during different gestational periods on neonatal ABR thresholds in pregnant guinea pigs. They exposed pregnant guinea pigs to noise during early, middle, and late

gestational stages, and conducted ABR measurements on postnatal days 1, 7, 14, and 28. The ABR thresholds were significantly higher in neonates born to guinea pig mothers exposed to noise during the middle and late gestational stage groups than in neonates of mothers in the early gestational stage group. These findings are not directly applicable for humans; however, they provide certain key evidence concerning fetal hearing loss caused by noise. Further studies are warranted to elucidate the exact mechanism.

In another study,<sup>[28]</sup> hearing was evaluated among infants exposed to acoustic noise because of magnetic resonance (MR) imaging in utero. Among 103 infants who underwent MR imaging in utero from 1999 to 2007, the results for 96 infants with completed hearing screening tests were evaluated. Thirty-four of these infants were admitted to a neonatal intensive care unit after birth, and the neonatal hearing screening results of the remaining healthy infants were compared against more than 16,000 OAE results as the reference. No significant differences were revealed. The authors concluded that 1.5 T MR noise did not have any significant effects on the hearing of infants born to mothers exposed to acoustic MR noise (115 dBA SPL for 15–30 minutes) during 1.5 T MR imaging in the second and third trimesters of pregnancy.<sup>[28]</sup> In another study<sup>[29]</sup> investigating the safety of 1.5 T MR in fetuses, 1.5 T MR had no unfavorable effects on neonatal hearing, intrauterine development, and birth weight in infants without risk factors for hearing loss, regardless of the timing and total duration of exposure. Abramowicz *et al.*<sup>[30]</sup> reported that sound waves in obstetric diagnostic ultrasonography may pose a minimal risk for a fetus, even when performed in line with as low as reasonably achievable (ALARA) principles and for the appropriate medical indication. In an in vitro study model measuring the sound radiating from an endoscopic lithotripsy device,<sup>[6]</sup> the investigators concluded that administering this procedure during pregnancy is unlikely to damage the hearing of a fetus. There are also studies concerning the effects of incubator noise in intensive care units on neonatal hearing, which have yielded different results. Garinis *et al.*<sup>[31]</sup> evaluated the effect of gentamicin and environmental noise level in neonatal intensive care unit on hearing screening tests. Their study determined that all infants were exposed to environmental noise levels exceeding the guidelines proposed by the American Academy of Pediatrics, and the authors observed a greater rate of high-frequency F2-region DPOAE referrals, particularly in association with cochlear dysfunction caused by noise and/or gentamicin. Based on these findings, the investigators suggested that adding higher frequency DPOAE assessments to the current hearing screening protocols in neonatal intensive care unit may improve the identification of infants at ototoxicity risk. Jacobson and Mencher<sup>[32]</sup> showed that intensive care noise was not a factor affecting neonatal hearing screening. Douek *et al.*<sup>[33]</sup> investigated the effects of incubator noise on

neonatal cochlea in guinea pigs and concluded that most incubators had harmful effects on the auditory functions of premature infants. In another study,<sup>[34]</sup> researchers investigated the association between prematurity, incubator noise, and impaired hearing; they found that incubator noise was slightly below the hazard limit of noise exposure. They also demonstrated no relationship between the length of incubator stay and hearing impairment.

In the present study, noise exposure during pregnancy had no unfavorable effect on the auditory function of the infants. This finding indicated that maternal skin, subcutaneous tissue, and the amniotic fluid in the uterus and surrounding the infant collectively provide an adequate barrier. When hearing screening tests were evaluated by stage, the rate of infants that passed the test at OAE1 was significantly higher among infants with in utero noise exposure than among infants without in utero noise exposure. These results suggested that the noise at exposure action levels (80–85 dB A) during pregnancy may contribute to auditory maturation of fetus. Furthermore, because the current neonatal hearing screening tests are not frequency-specific and are performed at a frequency range of 1–4 kHz, the possibility of not detecting hearing loss at <1 kHz or >4 kHz should be considered. Thus, mothers should be asked about maternal noise exposure during pregnancy when neonatal hearing screening tests are conducted, and infants with such in utero noise exposure should also be assessed by means of DPOAE for a frequency-specific investigation. The elucidation of the effects of in utero noise exposure warrants further studies evaluating neonatal hearing—in particular, studies with frequency-specific measurements.

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### Conflicts of interest

There are no conflicts of interest.

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