Research Article

Effect of Contralateral Ear Occlusion in Newborns on the Amplitude of Transient Evoked and Distortion-Product Otoacoustic Emissions in Noisy Environments

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Highlights

- Occluding the contralateral ear could improve the amplitude of OAE in newborns
- NICU noise has greater effect on OAE amplitude compared to white noises

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ABSTRACT

Background and Aim: Background noise, especially in noisy environments such as Neonatal Intensive Care Units (NICUs), can compromise the accuracy of Otoacoustic Emission (OAE) tests by activating the Medial Olivocochlear (MOC) reflex, which suppresses the OAE amplitudes. This study aimed to evaluate whether the contralateral ear occlusion can improve the OAE amplitudes of newborns in noisy environments.

Methods: Thirty full-term newborns with no signs of hearing loss were enrolled. The OAEs, including Distortion-Product OAE (DPOAE) and Transient Evoked OAE (TEOAE), were recorded in the presence of three noises (two white noises at 50 and 60 dB SPL, and one recorded NICU noise) without and with contralateral ear occlusion (using a soundproof headphone). The OAE amplitudes were compared between two open and non-occluded conditions using paired t-test.

Results: After occlusion of the contralateral ear, there was a slight overall enhancement in DPOAE and TEOAE amplitudes in the presence of all noise types, which was statistically significant based on the paired t-test results. This improvement was more considerable in the presence of NICU noise than in the presence of white noise. The improvement in TEOAE amplitude was not as remarkable compared to the DPOAE amplitude.

Conclusion: The contralateral ear occlusion can improve the DPOAE and TEOAE levels in newborns, probably by reducing the activation of the MOC reflex, which can improve the accuracy of OAE tests and reduce the false positive results for newborns in noisy environments, consequently lowering the further diagnostic costs and parental concerns.

Keywords: Auditory efferent system; olivocochlear system; newborns; transient evoked otoacoustic emission; distortion product otoacoustic emission

Introduction

Otoacoustic Emissions (OAEs) result from an active mechanism in the cochlea [1], and can be emitted spontaneously or in response to an external stimulus [2, 3]. OAEs provide valuable information about hearing loss, especially in newborns [4-6]. The OAE test serves as the initial step in identifying hearing loss and is widely recognized as a reliable hearing screening technique in many countries [7, 8]. Significant hearing loss is reported to affect approximately 4.6 out of 1000 normal-hearing babies [9]. Undiagnosed hearing loss can significantly impair language development and cognitive abilities [10]. Early hearing screening with Transient Evoked Otoacoustic Emissions (TEOAE) can help mitigate the adverse impacts of hearing loss. Therefore, increasing the validity and accuracy of the OAE test has always been important. Nevertheless, OAE responses may be influenced by factors such as background noise, the examiner's technique, or the presence of hearing loss. The Medial Olivocochlear (MOC) reflex is a factor that can affect OAE amplitude [11]. The MOC reflex originates from the Superior Olivocochlear (SOC) nucleus and is activated in contralateral moderate noise [11-13]. This reflex can play a significant role in reducing acoustic trauma and enhancing speech perception in noisy environments, a phenomenon known as MOC unmasking [14, 15]. MOC fibers form synapses on Outer Hair Cells (OHC) and engage an active cochlear mechanism through cholinergic synapses. This process inhibits amplification by inducing hyperpolarization in the OHCs, which, in turn, is expected to influence OAE amplitude. Notably, this reflex is observed in both adults and newborns [16-18]. Research indicates that the MOC reflex can diminish OAE amplitude in newborns by 0.3–2.7 dB, varying across different frequencies [19].

Newborn screenings are often conducted in patient rooms, clinical settings, or Neonatal Intensive Care Units (NICUs), where sound levels can range from 54 to 83 dB SPL [20], which is high enough to trigger the activation of the MOC reflex. The false-positive rate of TEOAE in early hearing screening of newborns has been reported to range from 1.2% to 19.5% [21]. False-positive results can impose additional burdens on healthcare systems and families, and cause stress and anxiety for parents. Papsin et al. [22] employed a method of covering the contralateral ear in order to prevent activation of the MOC reflex, resulting in a significant enhancement in OAE amplitude in adults. Considering the anatomical and developmental differences between adults and newborns, conducting a similar evaluation is essential to assess the practicality of this method in newborns, and if effective, it can be implemented in screening protocols to enhance test reliability and minimize false-positive outcomes in newborns. Therefore, this study aimed to evaluate whether attenuating sound to the contralateral ear of newborns can improve the amplitude of Distortion Product OAE (DPOAE) and TEOAE in noisy environments.

Methods

Participants

In this study, 30 full-term newborns (48 ears) aged 8-48 hours were examined after birth in a hospital setting. Some newborns woke up during the testing procedure, leading to their exclusion from the study. One of the primary causes for this was the probe displacement from one ear to the other. Parental consent was obtained for all participants, and the noise presented during testing was ensured to be safe for their hearing sensitivity. All newborns had an Apgar score of at least 7, were not at risk of hearing loss, and had standard weights ranging from 2.5 to 4.0 kg. All newborns passed bilateral OAE screening to exclude the presence of hearing loss. Moreover, middle ear function was assessed and confirmed using a wideband tympanometer (Titan, Interacoustics, Denmark), thereby excluding any conductive abnormalities. None of the newborns had a family history of hearing disorders.

Noises

Three types of noise were utilized in this study: white noise at 50 dB SPL, white noise at 60 dB SPL, and recorded NICU noise. The white noise signals were generated using Audacity software, while the NICU noise was recorded during the day in a NICU. Unlike standard white noise, NICU noise exhibited more dynamic characteristics, with sound levels ranging from 53.5 to 84.9 dB SPL. The mean stimulus level was 71.5 dB SPL, with a rapid response time of 200 ms. To prevent the activation of the Middle Ear Muscle Reflex (MEMR), all noise levels during the test were kept below 75 dB SPL. All noise signals were calibrated using the B&K 2250 L Sound Level Meter (SLM) under controlled experimental conditions. Noise presentations occurred in a free-field setup, with the speaker positioned one meter away from the SLM at a 0° azimuth.

Procedure

The following steps were done in this study: 1) TEOAE and DPOAE measurements in quiet, 2) TEOAE and DPOAE measurements in the presence of 50 and 60 dB SPL white noises with and without the contralateral ear occlusion, and 3) TEOAE and DPOAE measurements in the presence of NICU noise with and without the contralateral ear occlusion.

To activate the MOC reflex, newborns were exposed to three types of noises. Initially, TEOAE and DPOAE measurements were conducted using a diagnostic OAE tool (Otometrics, Denmark) in a silent environment with ambient noise kept under 25 dB SPL. To minimize the impact of probe placement, all test stages were carried out while the newborns were in sleep mode by an examiner. The newborns had recently been fed to maintain a calm state. TEOAE responses were measured using the click stimuli, while DPOAEs were recorded using DPgrams as a function of f_2 ($2f_1$–f_2). The DPgrams were calculated as the simple average of emission amplitudes across all 13 frequencies. Both TEOAE and DPOAE measurements were recorded in the presence of noise to evaluate MOC suppression on OAE amplitude. The noise was delivered through a speaker starting from 30 seconds prior to the test to activate the MOC reflex. While the noise was still playing, the contralateral ear was covered using a soundproof headphone (Baltic S41CE, UK). This setup was designed to attenuate incoming noise into the contralateral ear and prevent the activation of the MOC reflex in the test ear. The attenuation levels at various frequencies were sourced from the Baltic S41CE catalog. Additional verification was conducted in a pilot study using real ear measurements (Audidata Primus), establishing an average reduction of 22–23 dB. Following the occlusion of the contralateral ear, TEOAE and DPOAE tests were repeated under identical conditions.

Statistical analysis

The data were analyzed using inferential and descriptive statistics. A paired t-test was employed to assess the difference in DPOAE and TEOAE amplitudes between the two conditions (with and without the contralateral ear occlusion). A p-value of ≤ 0.05 was considered statistically significant. All statistical analyses were conducted in SPSS version 17. The data in this study were found to have a normal distribution.

Results

The contralateral ear occlusion led to small increases in TEOAE amplitudes, and the greatest increase was observed at NICU noise in the left ear. For DPOAEs, contralateral ear occlusion caused more noticeable amplitude increases compared to TEOAEs. The largest mean increase was seen at 60 dB SPL white noise in the right ear.

Comparison of transient evoked otoacoustic emissions

We compared the TEOAE amplitudes with and without the contralateral ear occlusion in the presence of three noise types: 50 dB SPL white noise, 60 dB SPL white noise, and NICU noise. In the presence of 50 dB SPL white noise, no significant differences were observed at most frequencies, except at 3000 Hz in the left ear ($p=0.05$) and 4000 Hz in the right ear ($p=0.025$). In the presence of 60 dB SPL white noise, a statistically significant difference was found only at 1000 Hz in the right ear ($p=0.015$). In the presence of the NICU noise, significant differences were found at 1000 Hz in both ears ($p=0.001$ for the right ear, $p=0.010$ for the left ear), and at 2000 Hz and 4000 Hz in the left ear ($p=0.033$ and 0.002, respectively).

Overall, the increase in amplitude after contralateral ear occlusion was about 0.03 dB in the right ear and 0.02 dB in the left ear in the presence of 50 dB SPL white noise. In the presence of 60 dB SPL white noise, the mean MOC suppression effect was 0.32 dB in the right ear and 0.29 dB in the left ear. In the presence of NICU noise, the enhancement reached 0.29 dB in the right ear and 0.58 dB in the left ear (Figure 1).

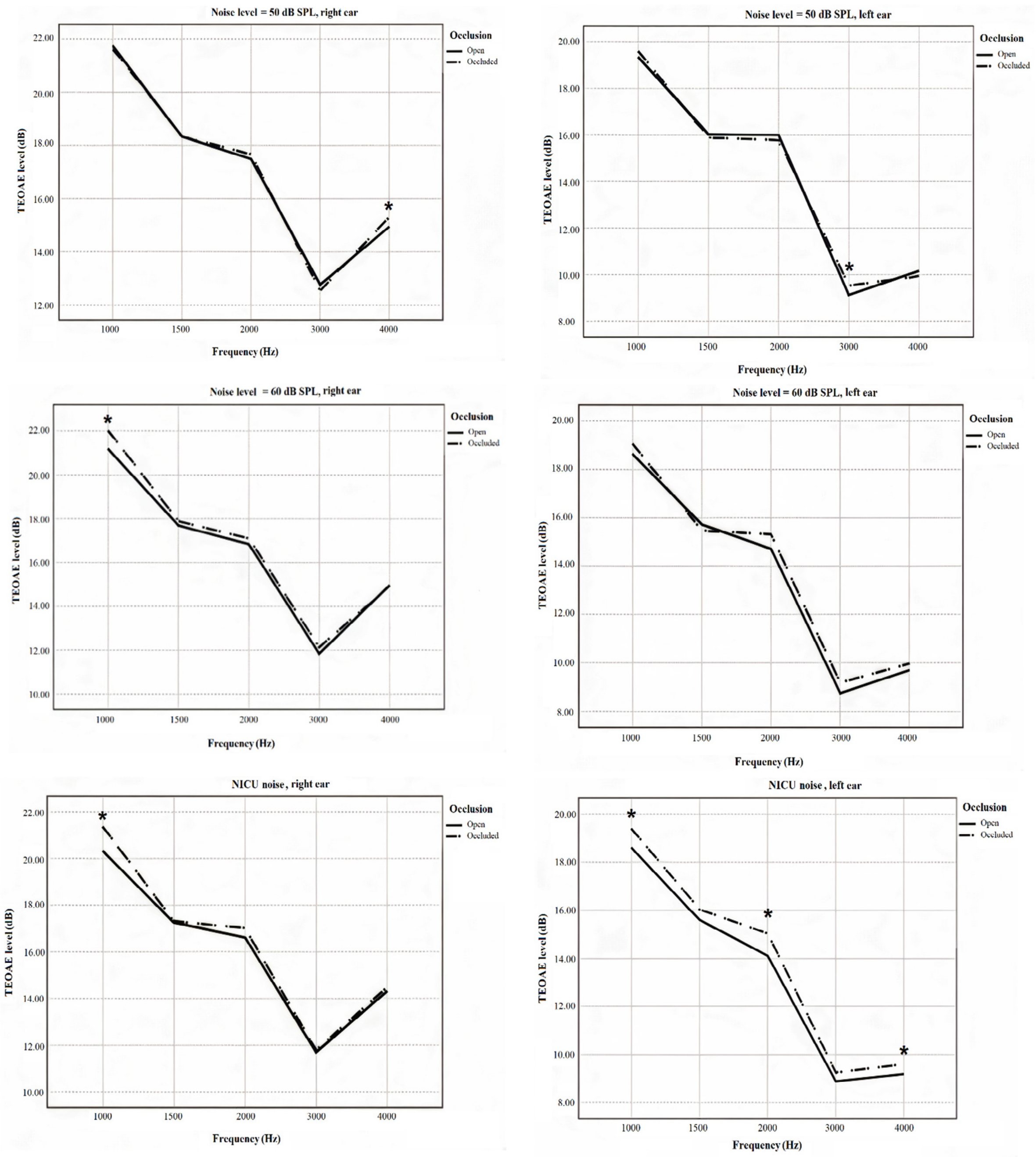

Figure 1. Comparison of transient otoacoustic emission amplitudes in both ears at different frequencies with and without contralateral ear occlusion in the presence of 50 and 60 dB SPL white noises and neonatal intensive care unit noise. TEOAE; transient otoacoustic emissions, NICU; neonatal intensive care unit

Comparison of distortion product otoacoustic emissions

The DPOAE amplitudes were also compared in conditions with and without the contralateral ear occlusion in the presence of three different noise types. The results showed the enhancement of DPOAE levels following contralateral ear occlusion in the presence of 50 dB SPL white noise. The results were not statistically significant across most frequencies, except at 800 Hz and 7998 Hz in the left ear. In the presence of 60 dB SPL white noise, more frequencies demonstrated significant improvements. Notably, a significant increase in DPOAE levels was observed at 1250 Hz in both ears ($p=0.001$ for the right ear, $p=0.13$ for the left ear), and at 1600 Hz, 2001 Hz, 6298 Hz, and 7998 Hz in the right ear

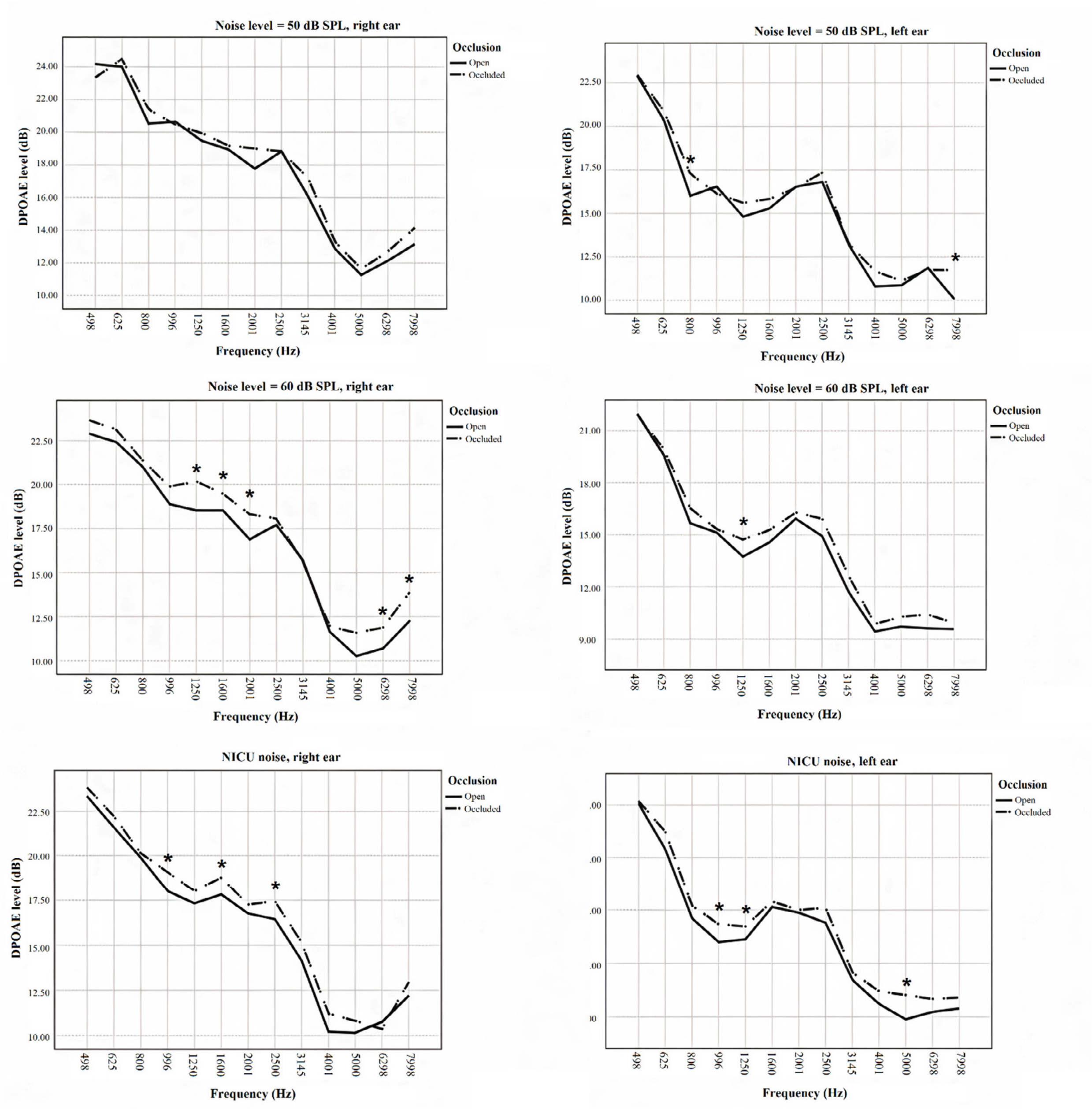

Figure 2. Comparison of distortion-product otoacoustic emission amplitudes in both ears at different frequencies with and without contralateral ear occlusion in the presence of 50 and 60 dB SPL white noises and neonatal intensive care unit noise. DPOAE; distortion product otoacoustic emissions, NICU; neonatal intensive care unit

(p=0.011, 0.001, 0.018, and 0.014, respectively). In the presence of NICU noise, significant DPOAE amplitude enhancement at 996 Hz in both ears (p=0.012 for the right ear, p=0.016 for the left ear), at 1600 Hz and 2500 Hz in the right ear (p=0.050 and 0.018, respectively), and at 1250 Hz and 5000 Hz in the left ear (p=0.049 and 0.028, respectively) were reported.

The mean difference in DPOAE amplitude between the open and occluded contralateral ear conditions was 0.45 dB in the right ear and 0.48 dB in the left ear in the presence of 50 dB SPL white noise. In the presence of 60 dB SPL noise, the measurements showed an improvement in DPOAE level by 0.88 dB in the right ear and 0.57 dB in the left ear. In the presence of NICU noise, the enhancement was 0.60 dB for the right ear and 0.67 dB for the left ear (Figure 2).

Discussion

The impact of contralateral acoustic stimulation on OAEs has been extensively studied in animal models

[23]. Surprisingly, these effects have not been thoroughly investigated in human newborns [22]. Understanding the effects of contralateral acoustic stimulation can enhance our knowledge of cochlear mechanics and the efferent system, potentially improving hearing screening procedures. Background noise in the OAE tests has long been a persistent challenge, particularly in newborn screenings. For valid and accurate results, ambient noise levels should remain below 65 dB A [2] as even a moderate noise can significantly prolong the test duration [2, 24]. Although clinical OAE diagnostics are typically conducted in controlled, sound-proof booths, there are often unavoidably noisy environments in hospitals. A previous study has demonstrated that background noise at the maternal bedside can reduce the TEOAE specificity by 4.2% [2]. Moreover, the OAE screening in the NICU has shown a false-positive rate of up to 8.5% [25]. As mentioned before, one key factor contributing to reduced OAE amplitudes is the MOC reflex. When activated by contralateral noise, the MOC reflex suppresses the OAE responses, diminishing signal amplitude. This effect can be mitigated by attenuating noise exposure to the contralateral ear. The primary objective of this study was to develop a practical approach to enhance the reliability of OAE testing in human newborns under real-world clinical conditions.

Consistent with the findings of Abdala et al. [1], our results demonstrated significant improvement in the DPOAE responses within the 1500–3000 Hz range. Our results are also somewhat in agreement with the findings of Chabert et al. [18], particularly in detecting suppression effects within the 2000–4000 Hz range. In Papsin et al.'s study [22], a single averaged value across the frequency range was employed to compare the OAE measurements, while our study adopted a more precise approach. We employed a higher frequency resolution for the OAE amplitude analysis, enabling statistical comparisons at each frequency by calculating the corresponding p-values. Although some studies have already proposed that the MOC function may be absent in newborns [26], our results provide evidence of measurable MOC suppression effects even in the early developmental stage. The observed robust suppression in mid-frequency ranges may reflect the role of the efferent system in speech perception, particularly in noise environments, as these frequencies align with critical components of the speech spectrum. Notably, the level of the suppression enhancement in this study exhibited a non-linear distribution across frequencies, consistent with the findings of Abdala and Keefe, and Papsin et al. [22, 27].

In the present study, statistical significance was not achieved at most frequencies in the TEOAE or DPOAE measurements. This contrasts with the findings of Papsin et al., who reported significant amplitude enhancements in both TEOAE and DPOAE responses when using 55 dB SPL white noise for the contralateral ear stimulation. This discrepancy may be due to developmental differences, as the newborns in our study demonstrate different response patterns compared to adults examined in Papsin et al.'s study [22]. Therefore, it may be attributed to several factors, such as age-related anatomical and physiological differences in middle ear development and ear canal characteristics, the maturation of the cochlear amplifier and transfer function [27], and differences in measurement protocols. Despite the statistically non-significant results at most frequencies, a consistent trend of amplitude enhancement was observed in both TEOAE and DPOAE measurements after contralateral ear occlusion by soundproof headphones. These findings support the previous reports indicating that the MOC suppression effects in humans can be subtle, with amplitude changes as small as 0.6 dB [28]; therefore, improvement of the OAE amplitude by at least 0.6 dB is supposed to be a result of the MOC reflex prevention even if it is not statically significant. Considering this criterion for MOC suppression, after the contralateral ear occlusion, many frequencies showed enhancement in amplitude compared to the open contralateral ear condition, which can be defined as the MOC reflex prevention. The slight increase in OAE amplitude can make a remarkable change in the TEOAE test by just covering the contralateral ear. It is a time-effective and safe method and can be used in hospitals or any noisy environment to reduce false positive results. It can be beneficial for clinicians who are working in the field of newborn screening.

Our findings demonstrate noise-dependent differences in the MOC reflex intensity. Consistent with previous reports [19, 3], higher noise levels can produce greater amplitude attenuation, while contralateral ear occlusion yields more pronounced amplitude attenuation. Specifically, the use of 60 dB SPL white noise resulted in more significant amplitude increases at more frequencies following occlusion compared to the 50 dB SPL white noise, suggesting insufficient MOC reflex activation at the 50 dB white noise in newborns, contrary to the report by Papsin et al. [22]. In our study, the contralateral ear occlusion led to significantly greater OAE amplitude enhancement in the presence of the NICU noise compared to the white noise exposure. This probably reflects its broader frequency spectrum (1000–8000 Hz) [29] and higher intensity levels. These results indicate that contralateral ear occlusion may be particularly beneficial in maternal bedside settings where the noise peak is 66–75 dB A [2] and in the NICUs with noise levels reaching 81 dB SPL [20].

There was a relatively small sample size in this study, and all participants were less than 48 hours old. It is recommended that future research be carried out with a larger sample size, including older newborns. Further research is also required to precisely evaluate the impact of MOC suppression on the false positive rate in neonatal hearing tests and to assess the duration of OAE testing in noisy environments, such as NICUs, with particular attention to the effect of contralateral ear occlusion on the test time.

Conclusion

Occluding the contralateral ear in newborns may help reduce the suppressive effects of the Medial Olivocochlear reflex, improving the Otoacoustic Emissions amplitude and enhancing test accuracy in noisy environments. This method has the potential to reduce false positives, minimize unnecessary follow-up testing, and lower parental concern.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by Ethic Committee of Iran University of Medical Sciences (Code No: IR.IUMS.REC.1401.597.)

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This work was found by the research committee at Iran University of Medical Sciences.

Authors' contributions

MY: Material preparation, data collection, study design, drafting the manuscript, interpretation; HHN: Drafting the manuscript, interpretation, suprevision; NR: Drafting the manuscript, data analysis; MM: Data collection; AB: Data analysis; MAS: data collection. All authors read and approved the final manuscript.

Conflict of interest

The authors have no conflicts of interest to declare.

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