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Mitun Kumar Paul
Associate Professor, Department of Otolaryngology and Head Neck Surgery, Gazi Medical College Hospital, Khulna, Bangladesh

Md. Zunaid Shakik
Assistant Professor, Department of Otolaryngology and Head Neck Surgery, Gazi Medical College Hospital, Khulna, Bangladesh

Purnendu Kishor Das
Assistant Professor, Department of Pediatrics, Gazi Medical College Hospital, Khulna, Bangladesh

Corresponding Author:
Mitun Kumar Paul
Associate Professor, Department of Otolaryngology and Head Neck Surgery, Gazi Medical College Hospital, Khulna, Bangladesh

Comparative analysis of behavioral observation audiometry and brainstem evoked response audiometry in early detection of hearing impairment in children: A study of 200 cases

Mitun Kumar Paul, Md. Zunaid Shakik and Purnendu Kishor Das

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Abstract
Early detection of hearing impairment in children is essential to prevent delays in speech, language, and cognitive development. This study aimed to evaluate the roles of Behavioral Observation Audiometry (BOA) and Brainstem Evoked Response Audiometry (BERA) in identifying hearing deficits in children, using a sample of 200 cases aged 0-6 years. Both audiometric methods were performed for each child, and results were compared to assess sensitivity, specificity, and concordance. BOA, a subjective assessment based on behavioral responses to sound, identified normal hearing in 60% of children, while 40% showed varying degrees of hearing loss, ranging from mild to severe. The most frequent category of impairment detected was mild hearing loss (20%). BERA, an objective electrophysiological test measuring auditory nerve and brainstem responses, detected normal hearing in 57.5% of children, while 42.5% exhibited hearing impairment. BERA detected a higher proportion of severe and profound hearing losses (10%) compared to BOA (6%), highlighting its superior sensitivity, particularly in cases that are difficult to assess behaviorally. The overall concordance between BOA and BERA was 87.5%, with discordances primarily occurring in children under 1 year, where behavioral responses were often subtle or inconsistent. Using BERA as the reference standard, BOA demonstrated 88% sensitivity and 95% specificity, with positive and negative predictive values of 92% each. Age-stratified analysis revealed that BOA performed reasonably well in infants under 1 year but was less reliable than BERA, which consistently provided accurate detection across all age groups. These findings indicate that while BOA is a useful initial screening tool, especially in very young children, BERA serves as a gold standard for early detection of hearing impairment, providing objective and reproducible results. Integrating both methods in pediatric audiological evaluation can enhance early diagnosis, allowing timely intervention and better developmental outcomes. The study underscores the importance of adopting a combined approach to maximize detection rates and ensure that children with hearing deficits receive appropriate management as early as possible.

Keywords: Hearing Impairment, Behavioral Observation Audiometry, Brainstem Evoked Response Audiometry, Early Detection, Pediatric Audiology, Children, Sensitivity, Specificity

1. Introduction
Hearing is a critical sensory modality essential for the development of speech, language, cognitive abilities, and social interaction in children. Hearing impairment in the early years can lead to significant delays in communication skills, academic performance, and psychosocial development if not identified and managed promptly [1]. According to the World Health Organization, approximately 34 million children worldwide suffer from disabling hearing loss, with the majority residing in low- and middle-income countries [2]. Early detection and intervention are therefore pivotal to improving developmental outcomes and quality of life. Various audiological methods have been developed to assess hearing function in infants and young children. Behavioral Observation Audiometry (BOA) is a subjective technique that evaluates infants' responses to auditory stimuli through observable changes in behavior, such as startle reflexes, eye movements, and limb activity [3]. BOA is particularly suitable for children under 6 months of age, where conventional audiometry is not feasible. However, its

reliability is limited by the subjective nature of observations, variability in infant responses, and the experience of the examiner [4]. On the other hand, Brainstem Evoked Response Audiometry (BERA) is an objective, electrophysiological method that measures neural activity along the auditory pathway from the cochlea to the brainstem in response to sound stimuli [5]. BERA provides quantitative information on hearing thresholds and can detect both unilateral and bilateral hearing losses, including mild to profound deficits [6]. Its non-reliance on behavioral cooperation makes it especially valuable for neonates, infants, and children with developmental or cognitive impairments. Although both BOA and BERA are used in clinical practice, their comparative roles in early detection of hearing impairment remain an area of active research. Several studies have demonstrated the complementary nature of these tests, suggesting that integrating subjective and objective assessments can enhance diagnostic accuracy [7,8]. Moreover, early audiological assessment enables timely interventions, such as hearing aids, cochlear implants, or speech therapy, which are crucial during the critical periods of auditory and language development [9,10]. This study aims to evaluate the efficacy of BOA and BERA in detecting hearing impairment among 200 children aged 0-6 years, analyzing their concordance, sensitivity, specificity, and age-related effectiveness. By identifying the strengths and limitations of each method, this research seeks to provide evidence-based recommendations for a structured approach to early pediatric hearing assessment, ultimately facilitating better developmental outcomes for children with hearing deficits.

2. Materials and Methods

Study Design and Setting

This was a cross-sectional observational study conducted over a period of 12 months at the Department of Otolaryngology and Head Neck surgery, Khulna Division, Khulna, Bangladesh from February 2024 to February 2025, assess hearing impairment in children using Behavioral Observation Audiometry (BOA) and Brainstem Evoked Response Audiometry (BERA).

Study Population

A total of 200 children aged 0-6 years, referred for suspected hearing loss, were enrolled. Inclusion criteria comprised children with no prior audiological evaluation, stable general health, and parental consent. Exclusion criteria included children with known neurological disorders, craniofacial anomalies affecting the ear, or those unable to cooperate for testing [4].

Audiological Assessment

Behavioral Observation Audiometry (BOA)

BOA was performed in a quiet, dimly lit room. Age-appropriate auditory stimuli, including speech sounds, pure tones, and environmental noises, were presented using a calibrated audiometer. Observed responses, such as eye widening, startle reflexes, or cessation of activity, were documented. Each response was repeated to confirm consistency. Hearing thresholds were categorized as normal, mild, moderate, or severe/profound according to standard pediatric criteria [3].

Brainstem Evoked Response Audiometry (BERA)

BERA was conducted using a portable evoked potential system. Electrodes were placed at the vertex, mastoid, and forehead after proper skin preparation. Click stimuli at varying intensities (20-90 dB HL) were delivered through earphones, and responses were averaged over 1,000-2,000 stimuli to obtain reproducible waveforms. Thresholds were determined by the lowest intensity eliciting identifiable wave V. Results were classified in the same categories as BOA [4,5].

Data Analysis

Data were analyzed using SPSS version 25.0. Frequencies and percentages described categorical variables. Concordance between BOA and BERA was evaluated using the Cohen's kappa coefficient, while sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of BOA were calculated using BERA as the reference standard. Age-stratified analysis was performed to assess method-specific efficacy in different pediatric age groups [6].

3. Results

3.1 Demographic Characteristics

The study included 200 children aged between 0 and 6 years. The age distribution and gender ratio are shown in Table 1.

Table 1: Age and Gender Distribution of Study Participants (N=200)

Age Group (years)	Male (n)	Female (n)	Total (n)
0-1	30	28	58
1-3	40	32	72
3-6	38	32	70
Total	108	92	200

The cohort consisted of 108 males (54%) and 92 females (46%). Infants under 1 year represented 29% of the study population, 1-3-year-olds accounted for 36%, and 3-6-year-olds formed 35%. This distribution allowed assessment of audiometric methods across early developmental stages.

3.2 Behavioral Observation Audiometry (BOA) Results

BOA testing was performed on all children. Responses were classified as normal hearing, mild impairment, moderate impairment, and severe/profound impairment.

Table 2: BOA Hearing Assessment Results (N=200)

Hearing Status	Number of Children (n)	Percentage (%)
Normal Hearing	120	60%
Mild Hearing Loss	40	20%
Moderate Hearing Loss	28	14%
Severe/Profound Loss	12	6%
Total	200	100%

BOA detected normal hearing in 60% of children, while 40% showed some degree of hearing impairment. Mild loss was the most common among affected children (20%). However, the subjective nature of BOA introduced variability in responses, especially in infants younger than 6 months.

3.3 Brainstem Evoked Response Audiometry (BERA) Results

BERA was performed to objectively confirm hearing thresholds. Results were classified similarly.

Table 3: BERA Hearing Assessment Results (N=200)

Hearing Status	Number of Children (n)	Percentage (%)
Normal Hearing	115	57.5%
Mild Hearing Loss	35	17.5%
Moderate Hearing Loss	30	15%
Severe/Profound Loss	20	10%
Total	200	100%

BERA confirmed normal hearing in 115 children (57.5%) and detected hearing impairment in 85 children (42.5%). Notably, BERA identified more cases of severe/profound hearing loss (10%) than BOA (6%), highlighting its superior sensitivity for severe cases.

3.4 Comparison of BOA and BERA

Table 4: Concordance between BOA and BERA (N=200)

Hearing Status (BOA vs BERA)	Concordant Cases (n)	Discordant Cases (n)
Normal Hearing	110	10
Mild Hearing Loss	30	10
Moderate Hearing Loss	25	3
Severe/Profound Loss	10	2
Total	175	25

Out of 200 children, 175 cases (87.5%) showed concordant results between BOA and BERA. Discordance occurred mainly in younger infants (<1 year) where BOA underestimated hearing loss due to subtle behavioral responses. This demonstrates BERA's reliability as an objective measure, especially in non-cooperative or very young children.

3.5 Sensitivity and Specificity Analysis

Using BERA as the gold standard

- **Sensitivity of BOA:** 88%
- **Specificity of BOA:** 95%
- **Positive Predictive Value (PPV):** 92%
- **Negative Predictive Value (NPV):** 92%

Paragraph Explanation

BOA showed high specificity but slightly lower sensitivity compared to BERA. This indicates that while BOA can reliably identify children without hearing loss, it may miss subtle or severe cases in very young infants. BERA remains the preferred method for early, objective detection.

3.6 Age-related Findings

Table 5: Detection Rates by Age Group

Age Group	BOA Detection Rate (%)	BERA Detection Rate (%)
0-1	75	85
1-3	85	90
3-6	95	98

BOA is relatively effective in infants under 1 year, but BERA consistently demonstrates higher detection rates across all age groups. The disparity in the youngest age group highlights the challenges of subjective audiometry in neonates and infants.

Discussion

Early identification of hearing impairment in children is crucial for minimizing developmental delays in speech, language, and cognitive skills. This study assessed 200 children aged 0-6 years using Behavioral Observation Audiometry (BOA) and Brainstem Evoked Response Audiometry (BERA) to determine their respective roles in early detection. The results highlight the complementary strengths of these two methods and emphasize the need for a combined diagnostic approach. BOA, a subjective method relying on observable behavioral responses to auditory stimuli, detected hearing impairment in 40% of children, with mild hearing loss being the most common (20%). These findings are consistent with previous studies reporting that BOA is effective for preliminary screening, particularly in infants under 6 months [6,7]. However, the method's reliability is inherently limited by the variability in infant responses and observer interpretation, leading to underestimation of moderate and severe hearing losses in younger age groups. Our study observed that discordant results between BOA and BERA primarily occurred in infants under 1 year, confirming that behavioral responses may be subtle and inconsistent in neonates [3]. In contrast, BERA provided an objective assessment and detected a slightly higher proportion of hearing impairment (42.5%), particularly identifying more severe/profound cases (10%) than BOA (6%). These results align with the established role of BERA as a gold-standard diagnostic tool, capable of assessing auditory thresholds regardless of patient cooperation [4,5]. The study's concordance rate of 87.5% between BOA and BERA underscores that while BOA is useful for early screening, BERA ensures accurate diagnosis and threshold determination. Similar findings have been reported by Maqbool *et al*., who emphasized the importance of electrophysiological testing in high-risk neonates and infants [6]. Age-related analysis revealed that BOA was relatively effective in infants under 1 year (detection rate 75%), but BERA consistently achieved higher detection rates across all age groups (85-98%). This supports previous recommendations that while BOA can serve as an initial assessment, definitive diagnosis should rely on objective measures such as BERA, particularly in children unable to provide reliable behavioral responses [7]. The integration of BOA and BERA provides several clinical advantages. BOA allows clinicians to observe naturalistic behavioral responses and assess auditory development in real-time, whereas BERA provides precise, reproducible thresholds and identifies neural pathway integrity. Early detection facilitates timely interventions such as hearing aids, cochlear implants, or speech therapy, which are critical during the sensitive periods of auditory and language development [8-10]. Limitations of this study include its single-center design and reliance on cross-sectional data. Longitudinal follow-up would allow assessment of developmental outcomes and the long-term efficacy of early interventions. Future research could also explore automated or combined audiological screening protocols to improve accessibility and accuracy in resource-limited settings. In our study, both BOA and BERA play vital roles in the early detection of hearing impairment. While BOA is suitable for preliminary screening, especially in neonates, BERA provides objective confirmation and accurate threshold determination. A combined approach, tailored to the child's age and developmental status, maximizes early detection and ensures timely intervention, ultimately improving communication and developmental outcomes.

Conclusion

Early detection of hearing impairment in children is crucial for timely intervention, which significantly impacts speech, language, and cognitive development. This study of 200 pediatric cases demonstrates that both Behavioral Observation Audiometry (BOA) and Brainstem Evoked Response Audiometry (BERA) play complementary roles in audiological assessment.

BOA serves as a practical, non-invasive screening tool, particularly useful in infants under 6 months, by providing insights into natural behavioral responses to auditory stimuli. However, its subjective nature and reliance on observable reactions may lead to underestimation of hearing loss, especially in moderate-to-severe cases.

In contrast, BERA provides an objective and reliable measure of auditory function, accurately identifying the degree and type of hearing impairment regardless of age or cooperation. It was shown to detect a higher proportion of moderate-to-severe hearing losses and demonstrated superior sensitivity and specificity compared to BOA.

The combined use of BOA and BERA ensures comprehensive evaluation: BOA allows early behavioral assessment, while BERA confirms diagnosis and determines precise auditory thresholds. Implementing both methods in a structured screening program facilitates early intervention with hearing aids, cochlear implants, or speech therapy, ultimately improving developmental outcomes for affected children.

In summary, while BOA is valuable for preliminary assessment, BERA should be considered the gold standard for objective diagnosis. A coordinated approach integrating both methods maximizes early detection, enabling timely clinical management and supporting optimal communication and developmental progress in children with hearing impairment.

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