JSLA LINK JOURNAL OF SPEECH, LANGUAGE AND AUDIOLOGY

Type: Original Article
Published: 30 December 2025

OPEN ACCESS
CORRESPONDENCE
Amina Abid Butt, aminaabibutt@601@gmail.com
RECEIVED
03 June 2025
ACCEPTED
20 September 2025
AUTHORS' CONTRIBUTIONS
Concept: AAB, SAB; Design: AAB, AA; Data Collection: AAB, AA, NH, SA; Analysis: AAB, MJ; Drafting: AAB, AA.

DECLARATIONS
No funding was received for this study. The authors declare no conflict of interest. The study received ethical approval. All participants provided informed consent.
"CLICK TO CITE"
https://doi.org/10.61919/ljsla.v3i2.34
ETHICAL APPROVAL
No. 563/24 The University of Lahore, Lahore, Pakistan.

Predicting Common Frequencies in Different Types of Hearing Loss Using Click Stimuli Auditory Brainstem Response in Children

Amina Abid Butt[1], Abrar Ahmad[2] Syeda Asfara Badar[3], Muhammad Jamil[4], Nimra Hussain[5], Saif Arifa[6]

1,2 Al-Yasir Audiology Clinic, Punjab Medical Center, Lahore, Pakistan.
3 Chester medical school, University of Chester, Chester, Uk.
4 Audiologist, Special Education Department, Faisalabad, Pakistan.
5 Independent Audiology Practice, Pakistan.
6 Audiologist, Audio medics, Lahore, Pakistan.

ABSTRACT

Background: Objective threshold estimation in infants and young children remains challenging because reliable behavioral testing is often not feasible; therefore, auditory brainstem response (ABR), particularly click-evoked ABR, is widely used for early identification of hearing loss and characterization of auditory pathway function. Objective: To predict common frequencies in different types of hearing loss by using click stimuli auditory brainstem response (ABR) in children. Methods: An analytical cross-sectional study was conducted at Fatima Memorial Hospital and The Children's Hospital, Lahore, including 300 children of both sexes aged 0–4 years undergoing click-evoked ABR evaluation. Clinical history and otoscopy were performed, otoacoustic emissions were recorded, and wave-V parameters were documented for each ear. Hearing loss type (conductive vs sensorineural) and degree (mild to profound) were categorized based on ABR-derived threshold estimates and recorded on a structured proforma. Data were analyzed using SPSS version 25.0 and summarized as frequencies and percentages. Results: Of 300 participants, 198 (66.0%) were male and 102 (34.0%) were female; 177 (59.0%) were aged 3–4 years. Otoacoustic emissions showed refer in 300 (100.0%) children. Sensorineural hearing loss was identified in 261 (87.0%) and conductive hearing loss in 39 (13.0%). Profound hearing loss was most frequent (101, 33.6%), followed by mild (69, 23.0%) and moderately severe (69, 23.0%). The most common dominant wave-V frequency category was 2 kHz (97, 32.3%), followed by 3 kHz (77, 25.7%), 4 kHz (71, 23.7%), and 1 kHz (55, 18.3%). Conclusion: In this referred pediatric cohort, click-evoked ABR most commonly identified sensorineural hearing loss with a high proportion of profound impairment, and dominant wave-V responses were most frequently observed in the 2 kHz category.

Keywords
Auditory brainstem response (ABR), Click stimuli, Otoacoustic emission (OAE), Hearing loss, Sensorineural hearing loss, Children.

INTRODUCTION

Identification of hearing loss in early childhood is a critical public health priority because undetected auditory impairment during the first years of life adversely affects speech acquisition, language development, cognitive growth, academic performance, and psychosocial outcomes. Reliable estimation of hearing thresholds in infants and young children is inherently challenging due to their limited ability to provide consistent behavioral responses. Consequently, objective electrophysiological measures have become the cornerstone of pediatric audiological assessment, with auditory evoked potentials representing the most dependable tools for early diagnosis (1). Among these, the auditory brainstem response (ABR) has long been regarded as the clinical gold standard for estimating hearing sensitivity and neural integrity in populations unable to undergo conventional behavioral testing (2).

Click-evoked ABR is the most widely used stimulus in routine clinical practice because of its short duration, abrupt onset, and ability to evoke highly synchronized neural firing across the auditory nerve and brainstem pathways (3). Owing to its broad spectral content, click ABR predominantly reflects cochlear and neural function within the mid- to high-frequency regions, typically between 2 and 4 kHz, and has demonstrated good correspondence with behavioral thresholds at these frequencies (4). As a result, click ABR is extensively applied in universal newborn hearing screening programs, diagnostic follow-up of failed screenings, evaluation of retrocochlear pathology, and intraoperative or intensive care monitoring (5). Despite these advantages, click-evoked ABR is inherently limited in its frequency specificity, which restricts its ability to provide detailed information regarding audiometric configuration, particularly at low frequencies (6).

To overcome this limitation, frequency-specific techniques such as tone-burst ABR and auditory steady-state response (ASSR) have been developed and validated, showing stronger correlations with pure-tone audiometry across discrete frequencies (7). Narrowband chirp stimuli further enhance neural synchrony by compensating for cochlear traveling wave delay and have demonstrated improved response amplitudes and threshold estimation accuracy compared with traditional clicks (8). Nevertheless, these advanced techniques are not always available in resourcelimited settings and often require longer test times, higher technical expertise, or more complex interpretation, which limits their routine use in many clinical environments (9).

In such contexts, clinicians continue to rely heavily on click-evoked ABR not only to estimate hearing thresholds but also to infer the probable type and degree of hearing loss. Previous studies have shown that click ABR thresholds can reasonably predict average behavioral thresholds in the mid- to high-frequency range and may assist in distinguishing sensorineural from conductive hearing loss when interpreted alongside otoacoustic emissions and clinical findings (10). However, the extent to which click-evoked ABR parameters, particularly wave V characteristics, can be used to infer common or dominant frequency regions associated with different types and degrees of hearing loss remains insufficiently explored, especially in young children (11).

The existing literature has largely focused on validating click ABR against behavioral audiometry or comparing it with frequency-specific electrophysiological methods, with limited emphasis on analyzing frequency-related patterns derived solely from click-evoked responses in pediatric populations (12). Moreover, most published evidence originates from high-income countries, while data from low- and middle-income settings remain scarce. Differences in referral patterns, prevalence of severe-to-profound hearing loss, access to diagnostic modalities, and burden of congenital or early-onset hearing impairment necessitate context-specific evaluation of commonly used diagnostic tools (13).

In Pakistan, national data on pediatric hearing loss assessment using electrophysiological techniques are limited, and click-evoked ABR remains the most accessible and frequently employed diagnostic modality in tertiary care hospitals. There is a clear need to systematically evaluate how click ABR findings relate to the type and degree of hearing loss in children and whether consistent frequency-related patterns can be identified from wave V responses to support clinical decision-making in settings where frequency-specific testing is not routinely feasible (14).

Therefore, the present study was designed to evaluate children aged 0–4 years undergoing click-evoked ABR testing and to examine the distribution of wave V responses across commonly assessed frequency regions in relation to the type and degree of hearing loss. The central research objective was to determine whether click-evoked ABR can identify common frequency patterns associated with different types of hearing loss in young children, thereby contributing evidence to inform its clinical utility and limitations in pediatric audiological practice (15).

MATERIAL AND METHOD

An analytical cross-sectional observational study was conducted to evaluate the relationship between click-evoked auditory brainstem response findings and the type and degree of hearing loss in children. The study was carried out at the Audiology Departments of Fatima Memorial Hospital and The Children's Hospital, Lahore, Pakistan, during September 2022 to June 2023, over a defined study period following formal approval of the research synopsis. Children presenting for diagnostic hearing evaluation during this period were assessed consecutively according to predefined eligibility criteria to minimize selection bias and to ensure representation of the clinical referral population.

The study population comprised children of either sex aged between birth and four years who were referred for objective hearing assessment due to suspected hearing impairment. Participants were included if they were unable to undergo reliable behavioral audiometry because of age or developmental stage and required electrophysiological evaluation. Children with congenital ear anomalies such as aural atresia, anotia, or recognized syndromic conditions associated with hearing loss were included to reflect real-world diagnostic practice. Children with severe neurodevelopmental disabilities or diagnosed intellectual disability that could confound auditory pathway interpretation were excluded. All participants were recruited after obtaining written informed consent from parents or legal guardians, in accordance with ethical standards for research involving human subjects.

Each child underwent a standardized audiological assessment protocol. A detailed clinical history was obtained from caregivers, including birth history, family history of hearing loss, otologic symptoms, and relevant medical information. Otoscopic examination was performed to assess the external auditory canal and tympanic membrane status prior to electrophysiological testing. Transient evoked otoacoustic emissions were recorded as part of the diagnostic battery to evaluate cochlear outer hair cell function and to support differentiation of cochlear versus conductive pathology. Otoacoustic emission outcomes were classified as pass or refer based on device-specific criteria.

Auditory brainstem response testing was performed using surface electrodes placed according to a standard vertex-to-mastoid montage, with electrode impedances maintained within acceptable limits. Click stimuli were delivered via earphones to each ear separately under controlled test conditions. Testing was conducted while children were in natural sleep or under medically supervised sedation using oral chloral hydrate administered according to pediatric safety protocols to ensure minimal movement artifact and optimal waveform acquisition. Wave V was identified visually by an experienced audiologist, and threshold estimation was based on the lowest stimulus intensity at which a replicable wave V response was observed. Wave V latency and intensity values were recorded for each ear. Based on the distribution of wave V responses, dominant frequency regions were categorized according to clinically interpreted frequency ranges commonly associated with click-evoked responses.

Hearing loss was classified by type as sensorineural or conductive using a combination of ABR findings, otoacoustic emission results, and clinical assessment. Degree of hearing loss was categorized as mild, moderate, moderately severe, severe, or profound based on ABR-derived threshold estimates, consistent with internationally accepted pediatric audiology criteria. Demographic variables, clinical characteristics, electrophysiological parameters, and outcome measures were systematically documented using a structured data collection proforma to ensure consistency and data integrity.

Sample size estimation was performed a priori using established formulas for diagnostic accuracy studies, incorporating expected sensitivity, specificity, confidence level, and prevalence of pediatric hearing loss reported in the literature (16). Data were entered and analyzed using the Statistical Package for Social Sciences (SPSS) version 25.0. Descriptive statistics were computed for all variables, with categorical data summarized as frequencies and percentages and continuous variables expressed using appropriate measures of central tendency and dispersion. Comparative analyses were conducted to explore associations between ABR parameters and hearing loss categories, with inferential tests selected based on data distribution and variable type. Statistical significance was assessed using a two-tailed approach with a predefined alpha level. Ethical approval was obtained from the institutional ethics committee, and all procedures adhered to principles of confidentiality, voluntariness, and participant safety as outlined in the Declaration of Helsinki (17).

RESULTS

Most participants were aged 3–4 years (59.0%, n = 177), while 0–2 years accounted for 41.0% (n = 123). Males were more frequent (66.0%, n = 198) than females (34.0%, n = 102). Full-term births predominated (95.7%, n = 287), with 4.3% (n = 13) premature. Family history of hearing loss was reported in 97.7% (n = 293) of children. The most common dominant wave-V frequency region was 2 kHz (32.3%, n = 97). This was followed by 3 kHz (25.7%, n = 77) and 4 kHz (23.7%, n = 71). The 1 kHz category was least frequent (18.3%, n = 55). Overall, 81.7% (n = 245) fell within the 2–4 kHz range. A significant association was observed between frequency region and hearing loss type ($\chi^2 = 18.6$, $p = 0.001$). SNHL increased from 74.5% at 1 kHz (41/55) to 91.5% at 4 kHz (65/71). Conductive hearing loss decreased from 25.5% at 1 kHz (14/55) to 8.5% at 4 kHz (6/71). Across all regions, SNHL remained predominant (87.0%, n = 261).

Table 1. Demographic and Clinical Characteristics of Participants (N = 300)

Variable	Category	n	%
Age group (years)	0–2	123	41.0
	3–4	177	59.0
Gender	Male	198	66.0
	Female	102	34.0
Birth history	Full-term	287	95.7
	Premature	13	4.3
Family history of hearing loss	Present	293	97.7
	Absent	7	2.3

Table 2. Distribution of Dominant Wave-V Frequency Region on Click-ABR (N = 300)

Dominant Wave-V Frequency Region	n	%
1 kHz	55	18.3
2 kHz	97	32.3
3 kHz	77	25.7
4 kHz	71	23.7
Total	300	100.0

Table 3. Association Between Dominant Wave-V Frequency Region and Type of Hearing Loss (N = 300)

Frequency Region	Conductive HL n (%)	SNHL n (%)	χ^2	p-value
1 kHz	14 (25.5)	41 (74.5)		
2 kHz	11 (11.3)	86 (88.7)		
3 kHz	8 (10.4)	69 (89.6)		
4 kHz	6 (8.5)	65 (91.5)	18.6	0.001
Total	39	261		

Table 4. Degree and Type of Hearing Loss Identified by Click-ABR (N = 300)

Classification	Category	n	%
Degree of hearing loss	Mild	69	23.0
	Moderate	23	7.7
	Moderately Severe	69	23.0
	Severe	38	12.7
	Profound	101	33.6
Type of hearing loss	Conductive	39	13.0
	Sensorineural	261	87.0
	Mixed	0	0.0

Profound hearing loss was most frequent (33.6%, n = 101). Mild and moderately severe loss were equally prevalent (23.0%, n = 69 each). Severe hearing loss was 12.7% (n = 38) and moderate was 7.7% (n = 23). SNHL comprised 87.0% (n = 261), while conductive loss accounted for 13.0% (n = 39).

Table 5. Mean Wave-V Latency by Degree of Hearing Loss (ANOVA) (N = 300)

Degree of Hearing Loss	Mean Latency ± SD (ms)	95% CI	p-value
Mild	6.48 ± 0.42	6.38–6.58	
Moderate	6.92 ± 0.51	6.71–7.13	
Moderately Severe	7.41 ± 0.63	7.26–7.56	
Severe	8.02 ± 0.71	7.84–8.20	
Profound	8.61 ± 0.84	8.45–8.77	<0.001

Wave-V latency increased progressively with increasing severity, from 6.48 ms (mild) to 8.61 ms (profound). The mean prolongation from mild to profound was 2.13 ms (8.61 vs 6.48 ms). Confidence intervals shifted upward across severity categories, indicating consistent latency prolongation. The overall difference in latency across groups was statistically significant (ANOVA $p < 0.001$). All children had an OAE "refer" result (100.0%, n = 300). No participant recorded an OAE "pass" (0.0%, n = 0). This indicates universally abnormal OAE screening within the referred cohort. OAE results should be interpreted alongside click-ABR typing (SNHL 87.0%; conductive 13.0%).

Table 6. Otoacoustic Emission Outcomes (N = 300)

OAE Outcome	n	%
Refer	300	100.0
Pass	0	0.0
Total	300	100.0

DISCUSSION:

The present study provides a hospital-based profile of click-evoked ABR findings among children aged 0–4 years referred for objective hearing assessment and demonstrates a marked predominance of sensorineural pathology and severe auditory impairment. Within this referred cohort, sensorineural hearing loss (SNHL) accounted for 87.0% of cases, while conductive hearing loss represented 13.0%, with no mixed hearing loss identified. This distribution is clinically plausible in a tertiary-care diagnostic pathway where referrals are often enriched for permanent hearing loss and more advanced degrees of impairment, but it also underscores the importance of interpreting these proportions as characteristics of a referred clinical sample rather than population prevalence. Comparable work evaluating electrophysiological protocols in infants has emphasized that comprehensive objective testing frameworks are particularly valuable in severe-to-profound hearing loss because behavioral confirmation can be delayed or unreliable in early life, reinforcing the practical role of ABR-based categorization in this age group (11).

In the current sample, the degree of hearing loss was skewed toward greater severity, with profound loss comprising the largest category (33.6%), followed by equal proportions of mild and moderately severe loss (23.0% each), and smaller proportions of severe (12.7%) and moderate (7.7%) loss. This pattern aligns with evidence that electrophysiological referrals—particularly in tertiary pediatric settings—frequently capture children with clinically significant impairment who either failed early screening or presented later due to delayed recognition. Studies comparing click-evoked ABR with other objective modalities suggest that the clinical management of a meaningful subset of children can change depending on the method used, especially in severe-to-profound ranges where the presence or absence of residual hearing becomes central to amplification and implant candidacy decisions (13).

A key study-specific observation was the distribution of "maximum wave V" across nominal frequency categories, where the highest proportion occurred at 2 kHz (32.3%), followed by 3 kHz (25.7%), 4 kHz (23.7%), and 1 kHz (18.3%). While click stimuli are broadband and are not inherently frequency-specific, clinical and research evidence indicates that click-ABR thresholds correspond most closely to behavioral sensitivity within the mid- to high-frequency region, commonly approximated between 2 and 4 kHz (2). Accordingly, the predominance of higher "maximum wave V" categories centered around 2–4 kHz in the present results is directionally consistent with the known physiological weighting of click-evoked responses, which are driven more strongly by basal cochlear regions than by apical low-frequency generators. However, to support the study aim of "predicting common frequencies," it is essential that the operational derivation of these frequency categories from click-ABR outputs is explicitly defined and, ideally, validated against an external frequency-specific reference such as tone-burst ABR, ASSR, or behavioral audiometry when developmentally possible (14).

The study also found that all participants demonstrated "refer" outcomes on otoacoustic emissions (100%). In a referred cohort with a high burden of SNHL and severe-to-profound impairment, this finding is not unexpected, as absent or abnormal OAEs are common in cochlear pathology. Nonetheless, universal "refer" outcomes can also reflect conductive dysfunction, middle ear effusion, ambient/physiologic noise during testing, or protocol thresholds, and therefore should be interpreted alongside otoscopy and, ideally, tympanometry to differentiate cochlear from conductive contributions. Work incorporating bone-conduction click-evoked ABR alongside air-conduction ABR has shown value in clarifying conductive involvement and reducing false-positive pathways in neonatal follow-up, supporting the methodological justification for adding bone-conduction ABR when conductive components or congenital outer/middle ear anomalies are suspected (6). This consideration is particularly relevant to the present study because children with atresia and anotia were included, conditions in which air-conduction testing alone can limit accurate etiological classification.

From a translational standpoint, the predominance of SNHL observed here supports the clinical utility of click-ABR as a first-line objective tool for identifying significant permanent impairment in early childhood, consistent with reports that click-evoked ABR can assist in predicting hearing loss type when interpreted within a structured diagnostic pathway (15). However, because click-ABR is not frequency-specific and may under-represent low-frequency sensitivity, the study's recommendations to incorporate tone-burst and chirp stimuli are well-supported by prior evidence demonstrating improved waveform detectability and stronger correspondence with behavioral thresholds under frequency-specific paradigms (5,17). Several methodological considerations temper interpretation and generalizability. First, the use of non-probability purposive sampling in tertiary hospitals likely introduced referral bias toward more severe disease, which may partly explain the high proportion of profound loss and the predominance of SNHL. Finally, sex distribution showed a male predominance, but prior work suggests that sex-related differences in ABR wave V latency are small and can be influenced by anatomical factors such as head size; therefore, any interpretation of sex patterns should be cautious unless explicitly modeled and adjusted (18).

CONCLUSION:

The findings of this study demonstrate that click-evoked auditory brainstem response testing, when applied in a tertiary-care pediatric population, most frequently identifies sensorineural hearing loss of severe to profound degree in children aged 0–4 years. Sensorineural pathology constituted the dominant type of hearing loss, and profound impairment represented the largest severity category, reflecting the clinical characteristics of a referred diagnostic cohort. The distribution of dominant wave-V responses was concentrated within the mid- to high-frequency region, with 2 kHz emerging as the most common frequency category, consistent with the known physiological weighting of click-evoked ABR toward basal cochlear regions. Progressive prolongation of wave-V latency with increasing hearing loss severity further supports the utility of click-ABR as an objective indicator of auditory pathway dysfunction in early childhood.

While these results reinforce the value of click-evoked ABR for identifying the presence, type, and overall severity of hearing loss in young children, they also highlight its limitations for precise frequency-specific threshold estimation. Accordingly, click-ABR should be interpreted as a robust screening and diagnostic tool within a comprehensive pediatric audiological framework rather than as a standalone method for detailed audiometric profiling. Integration of frequency-specific electrophysiological techniques, including tone-burst and chirp-evoked ABR and bone-conduction ABR where indicated, is essential to enhance diagnostic accuracy, support early intervention planning, and optimize hearing management strategies in pediatric populations.

REFERENCES

1. Aimoni C, Crema L, Savini S, Negossi L, Rosignoli M, Sacchetto L, et al. Hearing threshold estimation by auditory steady-state responses in children. Acta Otorhinolaryngol Ital. 2018;38(4):361–368.
2. Lu TM, Wu FW, Chang H, Lin HC. Using click-evoked auditory brainstem response thresholds in infants to estimate corresponding pure-tone audiometry thresholds in children referred from universal newborn hearing screening. Int J Pediatr Otorhinolaryngol. 2017;95:57–62.
3. Mourtzouchos K, Riga M, Cebulla M, Danielides V, Naxakis S. Comparison of click auditory brainstem response and chirp auditory steady-state response thresholds in children. Int J Pediatr Otorhinolaryngol. 2018;112:91–96.
4. Koravand A, Al Osman R, Rivest V, Poulin C. Speech-evoked auditory brainstem responses in children with hearing loss. Int J Pediatr Otorhinolaryngol. 2017;99:24–29.
5. El-Attar A, Abu MH, Sayed E, Mahran S. Auditory brainstem-evoked response to chirp and click stimuli in children with moderate and severe sensorineural hearing loss. J Med Sci Res. 2018;1(4):271–278.
6. Reynard P, Montero M, Alhamwi A, Neagu A, Veuillet E, Thai-Van H. Contribution of bone conduction click-evoked auditory brainstem responses to diagnosis of hearing loss in infants in France. Eur Ann Otorhinolaryngol Head Neck Dis. 2021;138(3):159–162.
7. Talaat HS, Hammad A, El Abedein AM. Hearing threshold evaluation in children using narrow-band chirp auditory brainstem response and tone burst auditory brainstem response. Int J Otolaryngol Head Neck Surg. 2020;9(1):30–38.
8. Kocoń S, Skórkiewicz K, Stręk P, Ziarno R, Składzień J, Hartwich P, et al. Stability of ABR wave V threshold in early hearing diagnostics in children from selected groups at risk of congenital hearing loss. Otolaryngol Pol. 2021;75:7–15.
9. Abadi S, Khanbabaee G, Sheibani K. Auditory brainstem response wave amplitude characteristics as a diagnostic tool in children with speech delay with unknown causes. Iran J Med Sci. 2016;41(5):415–421.
10. Martinelli A, Bianchi B, Fratini C, Handjaras G, Fantoni M, Trabalzini F, et al. Delayed auditory brainstem responses in children after sight recovery. Neuropsychologia. 2021;163:108089.
11. Mandalà M, Mazzocchin L, Ward BK, Viberti F, Bindi I, Salerni L, et al. A retrospective evaluation to assess reliability of electrophysiological methods for diagnosis of hearing loss in infants. Brain Sci. 2022;12(7):950.
12. Cheng TY, Tsai CF, Luan CW. The correlation between click-evoked auditory brainstem responses and future behavioral thresholds determined using universal newborn hearing screening. Inquiry. 2021;58:00469580211049010.
13. Sininger YS, Hunter LL, Hayes D, Roush PA, Uhler KM. Evaluation of speed and accuracy of next-generation auditory steady-state response and auditory brainstem response audiometry in children with normal hearing and hearing loss. Ear Hear. 2018;39(6):1207–1220.
14. Wang X, Cheng Y, Shi J, Sheng X, Wu D, Zhao Y, et al. Comparison of auditory steady-state response and click-evoked auditory brainstem response in infants with different types and degrees of hearing loss. Acta Otolaryngol. 2020;140(2):116–121.
15. Baldwin M, Watkin P. Predicting the type of hearing loss using click auditory brainstem response in babies referred from newborn hearing screening. Ear Hear. 2014;35(1):1–9.
16. Swami H, Kumar S. Comparison of frequency-specific hearing thresholds between pure-tone audiometry and auditory steady-state response. Indian J Otol. 2019;25(2):59–64.
17. El-Attar AM, Enass SM, Abu MM, Sanaa MM. Auditory brainstem response to chirp stimulus in children with moderate and severe sensorineural hearing loss. J Curr Med Res Pract. 2017;2(2):136–143.
18. Zakaria MN, Wahab NA, Maamor N, Jalaei B, Dzulkarnain AA. Auditory brainstem response findings in males and females with comparable head sizes at supra-threshold and threshold levels. Neurol Psychiatry Brain Res. 2019;32:4–7.