



Patients with unilateral tinnitus: evaluation of high-frequency audiometry and ABR results

HFA and ABR in unilateral tinnitus patients

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Abstract

Aim: This study aimed to investigate the pathology of tinnitus by analyzing Auditory Brainstem Response (ABR) waves and Extended High-Frequency Audiometry (EHFA) in patients with unilateral tinnitus without clinically detectable hearing loss.

Methods: In a retrospective case-control study, data from 48 patients with unilateral tinnitus were divided into two groups: ears with tinnitus and ears without tinnitus. ABR test results and EHFA test results were compared. The ABR test was applied in two different protocols, and the results were compared.

Results: Significant differences were observed in ABR wave latencies and amplitudes between ears with and without tinnitus. Specifically, the latency of the wave I was prolonged, and the wave III and V amplitudes were reduced in ears with tinnitus. EHFA results showed a higher number of ears exceeding the hearing threshold in tinnitus ears, although no significant difference was observed between ears with and without tinnitus. A comparison of ABR results across stimulus repetition rates revealed significant differences in most parameters.

Conclusion: The study emphasizes that distal pathologies of the 8th nerve should be investigated, and that changes in ABR latencies despite normal hearing thresholds should be considered in light of possible future degeneration. It also recommends specifying ABR stimulus repetition rates in research and applying EHFA in patients with unilateral tinnitus complaints to comprehensively assess tinnitus pathology.

Keywords

tinnitus, auditory brainstem response, hearing loss, high-frequency audiometry

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Introduction

Tinnitus is defined as the sensation of ringing in the ear or head in the absence of an acoustic stimulus. It affects approximately 10% of the global population. Although the majority of individuals with tinnitus exhibit some degree of hearing loss, there are instances where no clinically detectable hearing loss is present.¹⁻³ Nevertheless, this does not provide definitive evidence that individuals with tinnitus have unimpaired cochlear function. A number of theories have been put forth to explain this phenomenon, including the “hidden hearing loss” theory. Pure-tone audiometry is the most widely used clinical hearing test. The human auditory system is capable of detecting sounds within the frequency range of 20-20,000 Hz. However, the conventional pure tone audiometry test is limited to a frequency range of 125-8,000 Hz. In contrast, EHFA can measure the hearing threshold at 10-20 kHz, which may be indicative of the early stages of cochlear damage.⁴ Consequently, EHFA facilitates the early diagnosis and treatment of hearing disorders, thereby playing an important role in clinical audiology.⁵

One potential mechanism that may elucidate the underlying pathophysiology of tinnitus is abnormal neural activity in the cochlear nerve. The persistence of tinnitus despite cochlear nerve interruption indicates that retrocochlear auditory pathways and auditory cortex pathology may be involved.⁶⁻⁹ Auditory brainstem response (ABR) testing can be employed to objectively evaluate the neural pathway activation between the cochlear nerve and the inferior colliculus, thus allowing for the assessment of retrocochlear pathology.¹⁰

ABR tests are acoustically evoked signals that represent synchronized neural activation along neural pathways. It should be noted that ABR recordings are dependent on a number of variables, including sex, age, head size, and skull thickness.¹¹ In most published studies, ABR results from individuals with and without tinnitus were matched on these parameters. The use of poorly matched controls can often lead to misleading results. A review of the literature revealed considerable variability in the methodology employed in studies investigating tinnitus. There was considerable inconsistency across studies regarding differences in amplitude and latency between the tinnitus patient group and the control group. The most detailed findings across studies were a longer latency and reduced amplitude of wave I in the normal-hearing tinnitus groups compared with matched controls. However, it is important to note that the precision of wave I amplitude and latency measurements in the ABR is limited due to the bony protection of this recording.¹² To address the impact of individual variables and reduce heterogeneity, we conducted a direct comparison of ABR results and EHFA hearing thresholds between the tinnitus ear and the non-tinnitus ear within the same population. The objective of this study was to contribute to the understanding of both central and peripheral factors in tinnitus pathology.

Materials and Methods

Study Design and Population

This retrospective study was conducted from April to June 2023, using data from patients who presented with unilateral tinnitus at the ENT outpatient clinic of Ankara City Hospital between June 2020 and March 2024. A total of 48 patients meeting the inclusion criteria were identified.

Inclusion Criteria

Participants were adults aged 18–65 years with unilateral tinnitus and no history of clinically detectable hearing loss. All patients met the following criteria:

- Pure tone audiometry thresholds <25 dB HL across all frequencies (250–8,000 Hz)
- Normal acoustic reflex thresholds (70–100 dB SPL)
- Type A tympanogram
- Transient-evoked otoacoustic emissions recorded
- No vestibular, neurological, or psychological disorders
- No use of vestibulotoxic drugs
- Normal temporal MRI findings

Audiometric Measurements

Patients with pure tone averages ≥25 dB HL at frequencies below 8,000 Hz were excluded. High-frequency audiometric thresholds at 9,000 Hz, 10,000 Hz, and 11,200 Hz were recorded and categorized into normal (<25 dB HL) or impaired (≥25 dB HL).

ABR Testing

ABR tests were conducted using Neurosoft Neuro-Audio equipment under two protocols:

- Protocol 1: Click stimuli at 70 dB nHL, 27.1/s, alternating polarity.
- Protocol 2: Click stimuli at 70 dB nHL, 66.6/s, alternating polarity.

Absolute latencies for waves I, III, and V, as well as interpeak latencies (I–III, III–V, I–V), were recorded.

Ethical Approval

This study was approved by the Ethics Committee of Ankara City Hospital (Date: 08.02.2023, Decision No: E1/3240/2023).

Statistical Analysis

Data normality was assessed using the Kolmogorov–Smirnov test. Categorical variables were analyzed using Pearson’s Chi-square test, while parametric and non-parametric data were evaluated using independent t-tests, Mann–Whitney U tests, and Wilcoxon Signed Ranks tests, as appropriate. Correlations were determined using Spearman’s rho, and ROC curve analysis identified potential tinnitus predictors.

Reporting Guidelines

This study was reported in accordance with the STROBE guideline.

Results

Demographics

The study included 48 patients (19 women, 29 men) with a mean age of 50.92 ± 9.91 years. Tinnitus was reported in the left ear by 28 participants (58.3%) and in the right ear by 20 participants (41.7%).

ABR Protocol 1

Wave I latency was significantly prolonged in tinnitus ears compared to non-tinnitus ears ($P = .012$). Wave III and V amplitudes were significantly reduced in tinnitus ears ($P < .05$). However, interpeak latencies showed no significant differences (Table 1).

ABR Protocol 2

No significant differences were observed in any parameters between tinnitus and non-tinnitus ears (Table 1).

EHFA

High-frequency hearing thresholds at 9,000 Hz, 10,000 Hz, and 11,200 Hz showed no significant differences between tinnitus and non-tinnitus ears (Table 1).

Comparative Analysis of Protocols In tinnitus ears, wave III and V latencies were significantly longer in Protocol 2 compared to Protocol 1 ($P < .05$). Amplitude reductions were observed only for

Table 1. Comparison of Protocol 1 and Protocol 2 ABR Measurements Between Ears with Tinnitus and Ears without Tinnitus

ABR (ms) P1-P2	TINNITUS (+)	TINNITUS (-)	t/ Z	P value
	Mean ± SS or median (min-max)			
LI_P1	1.67 (1.23-2.46)	1.54 (1.20-2.05)	-2.504†	.012
AI_P1	0.11 (0.01-0.47)	0.08 (0.01-0.35)	-0.187†	.851
LIII_P1	3.86 ± 0.28	3.80 ± 0.25	1.060*	.292
AIII_P1	0.15 (0.01-0.27)	0.22 (0.04-0.39)	-2.678†	.007
LV_P1	5.74 (5.24-6.49)	5.68 (5.29-6.11)	-1.624†	.104
AV_P1	0.31 (0.01-0.58)	0.35 (0.15-0.67)	-2.171†	.030
AIII/I_P1	1.50 (0.13-5.00)	2.00 (0.54-6.25)	-2.368†	.018
AV/I_P1	0.19 (0.01-0.36)	3.94 (0.68-10.33)	-8.443†	<.001
AV/III_P1	1.97 (0.10-7.80)	1.74 (0.70-7.86)	-0.876†	.381
IPIII-I_P1	2.23 (1.38-2.62)	2.22 (1.65-2.88)	-0.561†	.575
IPV-I_P1	4.14 (3.08-4.45)	4.11 (3.41-4.86)	-0.213†	.832
IPV-III_P1	1.90 (1.64-2.62)	1.82 (1.28-2.69)	-0.773†	.439
LI_P2	1.78 (0.02-2.20)	1.80 (1.11-2.22)	-0.352†	.725
AI_P2	0.10 (0.01-0.31)	0.11 (0.01-0.28)	-0.220†	.826
LIII_P2	4.00 (0.24-4.56)	4.02 (3.60-4.58)	-0.598†	.550
AIII_P2	0.12 (0.03-0.32)	0.15 (0.02-0.32)	-0.513†	.608
LV_P2	6.03 ± 0.33	6.05 ± 0.37	-0.245*	.807
AV_P2	0.23 (0.07-0.68)	0.27 (0.06-0.70)	-1.496†	.135
AIII/I_P2	2.20 (1.40-4.17)	2.24 (1.96-2.91)	-0.271	.786
AV/I_P2	4.27 (3.45-6.32)	4.23 (3.68-5.29)	-0.099†	.921
AV/III_P2	2.00 (1.30-5.48)	1.97 (1.49-3.17)	-0.715†	.475
IPIII-I_P2	1.27 (0.47-10.00)	1.21 (0.30-11.00)	-0.652†	.514
IPV-I_P2	2.33 (0.41-5.50)	2.56 (0.26-9.00)	-0.725†	.468
IPV-III_P2	1.86 (0.40-8.25)	1.70 (0.62-10.67)	-0.249†	.803
HF PTA HL(dB)				
KHZ9	42.50 (0.00-70.00)	35 (0.00-70.00)	-0.309†	.757
KHZ10	45.00 (0.00-75.00)	45 (10.00-70.00)	-0.511†	.609
KHZ11.2	60.00 (0.00-80.00)	55.00 (0.00-80.00)	-1.120†	.263

(*) t value, Independent Samples t test; (†) Z value, Mann-Whitney U test, P < .05, Latency (L),Amplitude (A), Interpeak Latency (IP), Protocol(P), High Frequency Pure Tone Audiometry Hearing Level (HF PTA HL) Protocol 1(P1), Protocol 2(P2), LI_P1(wave I latency in Protocol 1), AI_P1(wave I amplitude in Protocol 1),

wave V in Protocol 2 (P = .002) (Table 2).

ROC Curve Analysis

Wave I latency (L1_P1) emerged as a significant predictor of tinnitus in Protocol 1 (P = .015). A latency >1.60 ms may indicate tinnitus with 63% sensitivity and 56% specificity (Table 3).

Discussion

The findings suggest that prolonged wave I latency in patients with tinnitus may reflect early degenerative changes in the eighth cranial nerve, potentially serving as a precursor to hearing loss. While our study did not find evidence supporting cochlear synaptopathy, variations in ABR parameters highlight the importance of standardizing testing protocols. Larger studies are required to validate these preliminary findings and refine diagnostic criteria.

The primary objective was to examine the delay and amplitude of ABR waves in patients presenting with unilateral tinnitus by comparing them with the healthy ear, to ascertain whether ABR results are influenced by the stimulus repetition rate, and to identify the presence of hearing loss in the ear with tinnitus in

EHFA. To this end, patients presenting with unilateral tinnitus were compared between the affected and unaffected ears to control for other potential confounding variables.

The outcomes of patients who underwent a click-stimulus ABR test with varying stimulus repetition rates, as outlined in Protocols 1 (27.1/sec) and 2 (66.6/sec), were analyzed. The measurements taken with the stimulus repetition rate for Protocol 1 revealed a significantly longer wave I latency in the ear with tinnitus (P = .012). Nevertheless, no significant difference was observed in the latencies of waves III and V. In the study conducted by Chen et al.¹³ no significant differences were found in ABR wave latencies and amplitudes. In the study conducted by Kehrle et al.,¹⁴ although the wave latencies were within the normal range, the latencies of waves I, III, and V were found to be significantly longer in the tinnitus group. The results of the comparisons revealed a significant prolongation of wave I latency in the ear with tinnitus in the present study (P = .012).

This leads us to hypothesize that tinnitus may be caused by pathologies of the eighth nerve. Despite normal hearing thresholds

Table 2. Comparison of Protocol 1 ABR data and Protocol 2 ABR Data in Ears with and without Tinnitus

ABR (ms)	TINNITUS (+)		TINNITUS (-)	
	Z	P value	Z	P value
L1_P2 / L1_P1	-1.031	.303	-3.937	< .001
A1_P2 / A1_P1	-0.053	.958	-1.138	.255
L3_P2 / L3_P1	-2.734	.006	-4.499	< .001
A3_P2 / A3_P1	-0.614	.539	-3.339	.001
L5_P2 / L5_P1	-3.890	< .001	-5.057	< .001
A5_P2 / A5_P1	-3.056	.002	-2.948	.003
A31_P2 / A31_P1	-0.913	.361	-2.759	.006
A51_P2 / A51_P1	-6.031	< .001	-2.862	.004
A53_P2 / A53_P1	-1.103	.270	-0.487	.626
IP31_P2 / IP31_P1	-1.369	.171	-0.017	.986
IP51_P2 / IP51_P1	-2.043	.041	-2.200	.028
IP53_P2 / IP53_P1	-2.065	.039	-2.781	.005

Wilcoxon Signed Rank test, $P < .05$, L1_P2(wave I latency in Protocol 2), A31_P2(amplitude ratio of wave III and wave I in Protocol 2), IP31_P2(interpeak latency of wave III and wave I in Protocol 2)

at speaking frequencies, the observed latency differences can be attributed to degenerative changes in the nerve that occur over time. This suggests that changes in the eighth nerve, which may lead to future hearing loss, may be an early symptom in patients with tinnitus.

In the study conducted by Roland Schaette et al,¹⁵ a decrease in wave I amplitudes was observed in the tinnitus group, whereas no significant difference was observed in wave V amplitudes. The researchers posited that these findings could be explained by central gain theory, which postulates that the excitability of the central auditory pathways increases to compensate for the reduction in input from the auditory nerve resulting from hidden hearing loss. Consequently, they proposed that there is no alteration in wave V amplitudes while wave I amplitudes decline. However, the study did not analyze the wave latencies. In their study, Shim HJ et al. ¹⁶ found no significant difference in amplitudes and were therefore unable to support the theory of ‘hidden hearing loss’. Additionally, the authors of the study proposed that the subjects in Schaette’s study were not homogeneous, which could have influenced the results due to the presence of various confounding variables. A comparison of sound tolerance levels was conducted to test the increased central gain theory, but no significant difference was found between ears with tinnitus and those without. A comparison

with the control group without tinnitus revealed a decrease in sound tolerance levels among the tinnitus patient group. It was proposed that this could be explained by the role of lateral olivocochlear efferents,¹⁷ which have the capacity to balance the activity of the cochlear nerve between the ears. In our study, as in Shim’s study, ears with tinnitus were compared with ears without tinnitus in the same subjects. No difference was found between the wave I amplitudes. In contrast, our study revealed a statistically significant reduction in wave III and wave V amplitudes in ears with tinnitus when assessed using Protocol 1. The measurements obtained with Protocol 2 did not yield any statistically significant differences, which aligns with the findings of Shim et al.¹⁶

In their study, the authors employed a protocol comprising a repetition rate of 13.3/sec and an intensity of 90 dB in their ABR measurements. The stimulus repetition rate is used in the differential diagnosis of retrocochlear pathologies to distinguish them from normal responses and cochlear pathologies. As the stimulus repetition rate increases, wave latencies increase. In cases of retrocochlear pathologies, this increase is more pronounced. Furthermore, higher stimulus repetition rates reduce wave amplitudes, leading to a progressive loss of waveform detail.¹⁸ The discrepancy in results between our study and that of Shim et al.¹⁶ may be attributed to significant differences between measurements obtained using different protocols within the same patient group. In his review study, Milloy et al. ¹² observed heterogeneity in the data on this subject and recommended that further studies be included in the literature to determine standard protocols and eliminate this heterogeneity.

In the study by Liberman et al. in 2016, the tinnitus group exhibited better hearing thresholds at high frequencies.¹⁹ In the present study, a comparison of high-frequency hearing thresholds revealed no significant difference between ears with tinnitus and those without. Furthermore, the study by Liberman et al. in 2017 found a correlation between high-frequency thresholds and SP/AP ratios on electrocochleography and reported a reduced incidence of cochlear synaptopathy in the tinnitus group.²⁰ This can be attributed to the fact that nerve fiber degeneration can take years to manifest and may require a significant period of time to induce alterations in the ABR. An additional potential explanation is that ABR may lack sufficient sensitivity to indicate synaptopathy, or that synaptopathy does not directly lead to the onset of tinnitus.

In conducting ROC-curve analysis of parameters that may serve as predictors of tinnitus, the ABR values L1_P1, A3_P1, A5_P1, and the A3_P1/A1_P ratio can be used in Protocol 1. Upon performing logistic regression analysis among these parameters, it was determined that wave I latency (L1_P1) is the most valuable parameter in ABR performed with Protocol 1 ($P = .020$). If the wave

Table 3. Analysis of Parameters That can Predict the Presence of Tinnitus

ROC-Curve analysis for parameters that can predict the presence of tinnitus					
Variable	Field	P	Cut-off value	Sensitivity %	Specificity %
L1_P1	0.644	.015	>1.60	63	56
A3_P1	0.342	.007	<0.18	60	58
A5_P1	0.372	.030	<0.34	56	58
A31_P1	0.360	.018	<1.79	64	65
Logistic Regression analysis for parameters that can predict the presence of tinnitus					
Variable	B	Wald	P	95% CI	
				Lower	Upper
L1_P1	-2.296	5.385	.020	0.014	0.700

I latency is above 1.60 ms and the patient does not have hearing loss between 250 and 8,000 Hz, it can be posited that the patient may have tinnitus with a sensitivity of 63% and a specificity of 56%. These findings demonstrate the potential of this objective parameter for detecting tinnitus, a subjective complaint. Further research is required, given the paucity of existing studies in this field.

Limitations

The study has a limited sample size and a retrospective design. Therefore, it doesn't have longitudinal follow-up or correlation with patient outcomes. The lack of electrocochleography findings, the gold standard for assessing cochlear health, is a limiting factor in the standardization of variables. However, selecting patients without cochlear pathology on MRI scans was intended to limit its impact on the variables.

Conclusion

Prolonged wave I latencies in tinnitus patients with normal hearing suggest possible degenerative changes in the eighth nerve, indicating a potential early sign of future hearing loss. However, our study found no evidence of cochlear synaptopathy associated with increased central gain in tinnitus subjects with normal audiograms. There was no statistically significant difference in high-frequency hearing thresholds, but larger studies covering higher frequency thresholds are needed. Differences in ABR comparisons highlight the sensitivity of measurements to changes in stimulus repetition rates, prompting further research in comparing ABR models and repetition rates. While elongated wave I latency in ABR Protocol 1 may predict the presence of tinnitus with 63% sensitivity, larger patient series studies are necessary to confirm this marker's validity.

Declarations

Animal and Human Rights Statement

All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments, or comparable ethical standards.

Informed Consent

Informed consent was waived.

Data Availability

The data supporting the findings of this study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare no conflict of interest.

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Author Contributions (CRediT Taxonomy)

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AI Usage Disclosure

The authors declare that no AI-assisted technologies were used.

Abbreviations

ABR: Auditory brainstem response

EHFA: Extended high-frequency audiometry

ENT: Ear, nose, and throat

HL: Hearing level

MRI: Magnetic resonance imaging

ROC: Receiver operating characteristic

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