



Research Article

Clinical Utility of the Tamil Speech-in-Noise Test for Detecting Hidden Hearing Loss in Tinnitus with Normal Audiograms: Insights from Behavioral and Electrophysiological Measures

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Highlights

- Tamil SIN test detects hidden hearing loss in tinnitus with normal audiograms
- OAE and ABR confirm subclinical cochlear and neural dysfunction
- Multimodal protocol improves early detection of suprathreshold deficits

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ABSTRACT

Background and Aim: Tinnitus often occurs in individuals with normal audiograms and may reflect Hidden Hearing Loss (HHL). Conventional audiometry fails to detect these suprathreshold deficits. This study evaluated the clinical utility of a validated Tamil Speech-in-Noise (SIN) test, supported by Otoacoustic Emissions (OAEs) and Auditory Brainstem Responses (ABRs), in detecting HHL in tinnitus patients.

Methods: Thirty native Tamil-speaking adults were recruited: 15 with chronic bilateral tinnitus and 15 matched controls. All had normal hearing thresholds. Participants underwent the Tamil Speech-in-Noise (SIN) test, Transient Evoked Otoacoustic Emissions (TEOAEs), Distortion Product Otoacoustic Emissions (DPOAEs), and click-evoked Auditory Brainstem Response (ABR). Group differences were analyzed using independent-sample t-tests.

Results: The tinnitus group showed significantly higher Signal-to-Noise Ratios at 50% correct (SNR-50) values and Signal-to-Noise Ratio (SNR) loss compared to controls, indicating impaired SIN perception. Both DPOAEs and TEOAEs were significantly reduced across frequencies, confirming cochlear dysfunction despite normal audiograms. ABR analysis revealed delayed wave I and wave III latencies, with marginal prolongation of wave V, indicating early auditory nerve involvement.

Conclusion: Tinnitus patients with normal audiograms demonstrate measurable auditory deficits, reflecting HHL. The Tamil SIN test, complemented by both OAE and ABR, provides a culturally appropriate and sensitive protocol for early detection. These findings highlight the limitations of pure-tone audiometry and support integrating multimodal assessments into tinnitus evaluations.

Keywords: Tinnitus; hidden hearing loss; Tamil speech-in-noise test; auditory brainstem response; otoacoustic emissions



Introduction

Tinnitus, defined as the perception of sound in the absence of an external source, is a common auditory phenomenon affecting 10–15% of adults worldwide. In approximately 2% of cases, tinnitus becomes chronic and significantly debilitating, contributing to sleep disturbances, anxiety, depression, and reduced quality of life [1–3]. The condition poses a substantial public health burden, with socioeconomic and psychological implications, and remains a challenge for both diagnosis and management. Although tinnitus is frequently associated with sensorineural hearing loss, a significant subset of individuals presents with persistent tinnitus despite clinically normal pure-tone audiometric thresholds [4–6]. This discrepancy highlights the limitations of standard audiometry in detecting subtle auditory dysfunction that can adversely affect real-world listening.

The concept of Hidden Hearing Loss (HHL) has emerged to describe suprathreshold auditory deficits that are not captured by conventional hearing tests. HHL is often linked to cochlear synaptopathy, a condition characterized by the degeneration of synapses between inner hair cells and low-spontaneous-rate auditory nerve fibers. These fibers play a crucial role in encoding complex sounds, particularly in noisy environments, and their dysfunction can impair temporal processing and neural synchrony [7, 8]. Individuals with HHL typically exhibit normal hearing thresholds in quiet but report difficulties in understanding speech in background noise, suggesting that standard audiometric measures fail to capture functionally relevant deficits [9, 10].

Speech-in-Noise (SIN) testing has gained prominence as a functional measure of auditory processing, providing insights into real-world hearing abilities. Performance in SIN tasks is influenced by linguistic familiarity, cognitive load, and auditory temporal resolution, underscoring the importance of native-language assessments for accurate evaluation [11–13]. To address this gap, a culturally and linguistically appropriate Tamil SIN test was independently developed and validated by the author [14]. The test comprises phonemically balanced, semantically unpredictable sentence lists presented in speech-shaped noise, stratified by age, and has demonstrated high internal consistency and reliability. Its development fills a critical need for regionally relevant diagnostic tools capable of detecting

suprathreshold auditory deficits in Tamil-speaking populations.

Objective measures complement behavioral testing by revealing physiological alterations that may underlie tinnitus in individuals with normal audiograms. Distortion Product Otoacoustic Emissions (DPOAEs) and Transient Evoked Otoacoustic Emissions (TEOAEs) provide sensitive indicators of outer hair cell function and cochlear integrity, detecting early subclinical changes even when pure-tone thresholds are within normal limits [15–17]. DPOAEs, particularly when fine-structure analysis is used, can reveal frequency-specific cochlear dysfunction, while TEOAEs are valuable for assessing mid-frequency outer hair cell status. These measures offer a non-invasive means of evaluating peripheral auditory function and can identify subtle deficits that contribute to impaired auditory clarity and speech-in-noise perception.

Auditory Brainstem Response (ABR) testing further extends diagnostic resolution by assessing neural conduction along the auditory nerve and brainstem pathways. In HHL, prolongation of wave I latency or reductions in amplitude reflect partial deafferentation or neural desynchrony [6, 11]. ABR results, in combination with SIN and OAE findings, provide converging evidence of hidden auditory dysfunction, offering a comprehensive view of both perceptual and physiological deficits.

Despite growing recognition of these tools, few studies have integrated native-language SIN testing, OAE fine structure, and ABR within a single clinical model, particularly in linguistically underrepresented populations.

The present study represents the first effort to examine tinnitus in individuals with normal audiograms using the Tamil SIN test alongside electrophysiological measures. The study aimed to evaluate the clinical utility of the Tamil SIN test in detecting hidden auditory deficits and hypothesized that, compared to age- and gender-matched controls, tinnitus patients would demonstrate poorer SIN performance, reduced OAE amplitudes, and prolonged ABR wave latencies despite clinically normal hearing thresholds.

Methods

Study design and participants

This prospective case-control study included 30 native Tamil-speaking adults aged 20 to 50 years. The

tinnitus group comprised 15 individuals reporting mild to chronic subjective bilateral symmetrical tinnitus for more than six months. The control group included 15 age- and gender-matched individuals with no history of tinnitus or auditory complaints. All participants were functionally literate in Tamil, ensuring adequate comprehension of the speech-in-noise test materials. Participants were screened to confirm cognitive and linguistic competence for test participation, which included a brief case history to rule out neurological disorders, speech-language impairments, or other conditions affecting test performance, and confirmation that Tamil was the primary language used in daily communication.

Inclusion criteria

All participants had normal bilateral and symmetrical pure-tone thresholds (≤ 25 dB HL) across octave frequencies from 250 to 8000 Hz and normal middle ear function, confirmed by type A tympanograms. Exclusion criteria included any history of middle ear pathology, otologic surgery, significant occupational or recreational noise exposure, use of ototoxic medications, neurological or psychiatric illness, and speech-language disorders. Informed written consent was obtained from each participant, and the study was approved by the Institutional Ethics Committee. Detailed participant demographics, including age, sex distribution, and inclusion criteria, are summarized in Table 1.

Audiological evaluation

Pure-tone audiometry was conducted in a sound-treated room using a calibrated Interacoustics AD528 audiometer (Interacoustics, Denmark). Air- and bone-

conduction thresholds were measured according to standard clinical procedures. Speech Reception Thresholds (SRTs) and Speech Identification Scores (SIS) were obtained to ensure auditory clarity and support participant inclusion. Symmetrical hearing was defined as an interaural threshold difference not exceeding 5 dB HL at any test frequency between 250 Hz and 8 kHz. Responses from the right and left ears were averaged to obtain a single representative measure of auditory function per participant.

Tinnitus handicap inventory

A preliminary Tamil version of the Tinnitus Handicap Inventory (THI) was developed using a forward-backward translation method. Two bilingual experts independently translated the English version into Tamil, and a reconciled version was back-translated into English by another bilingual professional. An expert panel of audiologists and linguists reviewed the translation for semantic and cultural accuracy. The pre-final version was pilot-tested with five native Tamil speakers with tinnitus for clarity and finalized for this study. The THI was administered to the tinnitus group ($n=15$) to assess emotional and functional impact (score range 0–100). Internal consistency was good (Cronbach's $\alpha=0.83$). Figure 1 shows the distribution of THI scores and severity levels among the tinnitus group.

Speech-in-noise test

Speech-in-noise perception was assessed using the Tamil Speech-in-Noise (SIN) test, independently developed and validated by the author. The test comprises phonemically balanced, linguistically appropriate, and semantically unpredictable sentences. A subset of

Table 1. Participant demographics and inclusion criteria

Parameter	Tinnitus group (n=15)	Control group (n=15)	Inclusion criteria
Age (years), mean $\pm$ SD	35.0 $\pm$ 8.70	34.80 $\pm$ 8.50	Age range 20–50 years
Gender distribution (male: female)	Male: 8 (53%), female: 7 (47%)	Male: 8 (53%), female: 7 (47%)	Matched
Hearing thresholds	≤ 25 dB HL (250–8000 Hz)	≤ 25 dB HL (250–8000 Hz)	Pure-tone thresholds within normal limits
Middle ear function	Type A tympanogram	Type A tympanogram	Normal middle ear status
Tinnitus duration	>6 months	N/A	Chronic subjective tinnitus (for the tinnitus group)
Noise exposure history	None	None	No significant occupational/recreational noise exposure
Otologic surgery/pathology	None	None	No prior otologic surgery or active ear pathology

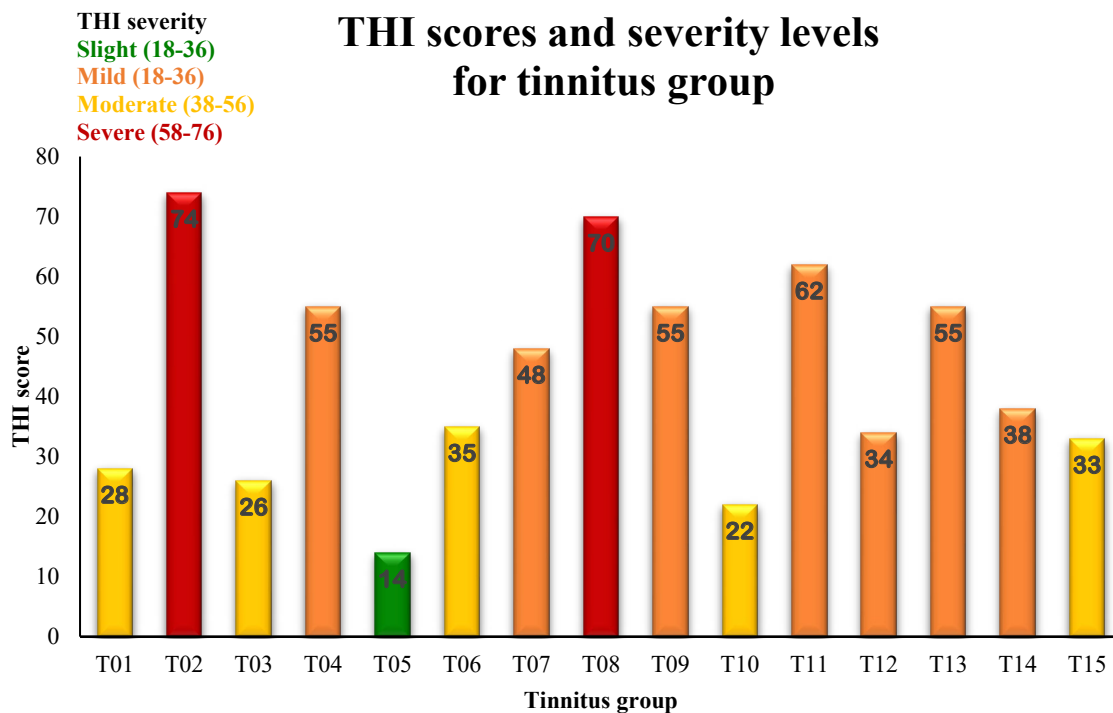


Figure 1. The graph shows the results of the tinnitus handicap index in the patient group with tinnitus. THI; tinnitus handicap index

seven validated lists (lists 1, 4, 5, 10, 13, 17, 20) was used, based on equivalence and optimal performance characteristics identified in the original validation study. Each list was presented at Signal-to-Noise Ratios (SNRs) ranging from +5 dB to -10 dB in 2.5 dB steps using Alvin software. Stimuli were calibrated using a Brüel & Kjær sound level meter and artificial ear to ensure consistent presentation at 65 dB SPL.

Sentences were delivered binaurally through calibrated Sennheiser HD 202 headphones in a sound-treated room. List order was randomized for each participant, and participants repeated each sentence aloud. Each sentence contained four target keywords, scored from 0 to 4 based on correct repetition, for a maximum of 28 points per list. Responses were audio-recorded and scored offline by two trained examiners independently. The SNR-50, representing the SNR at which 50% of keywords were correctly identified, was calculated using logistic regression.

Otoacoustic emissions

OAEs were recorded monaurally from both ears using the Neuro-Audio system (Neurosoft, Russia) to assess cochlear outer hair cell function. Amplitudes from right and left ears were averaged to yield a single representative measure per participant.

TEOAEs were elicited using nonlinear click stimuli at 80 dB SPL and analyzed for signal-to-noise ratio and waveform reproducibility across 1–5 kHz. DPOAEs were recorded with primary tone pairs ($f_2/f_1=1.22$) at 65 dB SPL, and fine-structure responses were measured across 900 Hz to 5000 Hz. Automated probe calibration ensured accurate stimulus delivery. The combination of TEOAE and fine-structure DPOAE data provided a comprehensive, non-invasive assessment of peripheral auditory function.

Auditory brainstem response

Click-evoked ABRs were recorded using the Neuro-Audio system (Neurosoft, Russia) to evaluate auditory nerve and brainstem pathway integrity. Recordings were collected monaurally using ER-3A insert earphones. Latencies were averaged across ears to generate a single composite measure per participant. Broadband click stimuli were presented at 70 dB nHL using alternating polarity with a repetition rate of 21.1 clicks per second, and responses were averaged over 2000 sweeps. Absolute latencies of waves I, III, and V, interpeak latencies (I-III, III-V, I-V), and Interaural Latency Difference for wave V (ILD-V) were measured. All waveforms were independently marked by two experienced audiologists, and discrepancies were resolved by consensus.

Statistical analysis

Data were analyzed using SPSS software (IBM Corp., Version 21). Descriptive statistics were calculated for demographic, behavioral, and electrophysiological measures. Independent-sample t-tests compared SIN performance, OAE amplitudes, and ABR latencies between control and tinnitus groups. Significance was set at $p < 0.05$. Effect sizes for significant differences were calculated using Cohen's d , with values of approximately 0.2, 0.5, and 0.8 interpreted as small, medium, and large effects, respectively.

Results

Calculation of Signal-to-Noise Ratio at 50% correct across lists

SNR-50 values were obtained for both the control and tinnitus groups using seven equivalent Tamil Speech-in-Noise sentence test lists. The SNR-50 value reflects the signal-to-noise ratio at which a listener can correctly recognize 50% of the target speech material. Across all seven lists, the control group consistently demonstrated better performance, reflected in more negative SNR-50 values, compared to the tinnitus group. Mean SNR-50 values for each list are summarized in Table 2.

Statistical comparisons using independent samples t-tests revealed significant differences between the two groups for all seven lists. The largest effects were observed in list 1 ($t=4.3$, $p=0.001$, $d=1.59$) and list 6 ($t=4.0$, $p=0.001$, $d=1.72$), followed by list 2 ($t=3.9$, $p=0.001$, $d=1.40$). Lists 3, 4, 5, and 7 also showed large effects ($d=0.98$ – 1.11), confirming consistent deterioration in the tinnitus group. These results indicate

that tinnitus, even in individuals with normal audiometric thresholds, is associated with reduced ability to perceive speech in noise.

Signal-to-Noise Ratio loss

To evaluate clinical relevance, SNR loss was calculated using an adapted version of Tillman and Olsen's [18] method. SNR loss was computed from the group mean SNR-50 values, in line with the fixed-SNR design of the Tamil SIN test and the reference method described in the original validation study [14]. The reference value was computed as the starting SNR (+5 dB) plus half the step size (1.25 dB), yielding 6.25 dB.

Each Tamil SIN sentence contained four keywords, with an adaptive step size of 2.5 dB. Group-wise SNR loss was calculated by subtracting the mean SNR-50 value from the reference:

$$\text{Control group: } 6.25 - (-5.65) = 11.90 \text{ dB}$$

$$\text{Tinnitus group: } 6.25 - (-4.59) = 10.84 \text{ dB}$$

Contrary to expectations, the control group showed higher SNR loss, which reflects better performance since more negative SNR-50 values indicate superior speech-in-noise recognition. The tinnitus group required higher SNRs for 50% accuracy, indicating poorer suprathreshold processing despite normal pure-tone hearing. These results highlight subclinical auditory deficits and the diagnostic value of language-specific SIN testing.

Distortion product otoacoustic emissions

DPOAEs were recorded at seven stimulus frequencies from 889 Hz to 5714 Hz to assess outer

Table 2. Comparison of Speech-in-Noise Recognition Threshold at 50% correct scores between the control and tinnitus groups: statistical comparison of means.

Lists	Control group SNR-50 (mean±SD)	Tinnitus group SNR-50 (mean±SD)	T	P	Cohen's d
List 1	-5.94±0.88	-4.50±0.93	4.30	0.001	1.50
List 2	-5.55±0.74	-4.52±0.74	3.90	0.001	1.40
List 3	-5.57±0.57	4.65±1.20	2.50	0.010	0.90
List 4	-5.88±0.85	-4.84±1.00	2.30	0.020	1.10
List 5	-5.47±0.60	-4.69±0.90	2.90	0.050	1.00
List 6	-5.93±0.89	-4.55±0.70	4.00	0.001	1.70
List 7	-5.49±1.01	-4.41±1.00	2.60	0.010	1.00

SNR-50; signal noise ratios at 50% correct

hair cell function. Responses were averaged across ears for each participant. The control group exhibited consistently higher DPOAE amplitudes across all frequencies, with significant differences at each frequency ($t=2.25-7.2$, $p=0.03-0.001$) and large to very large effect sizes ($d=0.94-2.90$), as shown in Table 3. The largest differences were observed at higher frequencies, particularly 4444 Hz and 5714 Hz, indicating frequency-dependent outer hair cell dysfunction despite normal audiograms.

Transient evoked otoacoustic emissions

TEOAEs were measured at five stimulus frequencies from 1000 Hz to 5000 Hz. Responses were averaged across ears for each participant. The control group showed higher amplitudes across all frequencies, with statistically significant differences at all bands ($t=3.5-9.3$, $p\leq 0.001$) and large to very large effect sizes ($d=1.33-3.79$), as shown in Table 4. Reduced TEOAE

amplitudes in the tinnitus group indicate widespread cochlear dysfunction, even with normal pure-tone thresholds.

Auditory brainstem response

ABRs were analyzed to evaluate neural conduction across the auditory brainstem. Latencies were averaged across ears for each participant. The tinnitus group demonstrated prolonged wave I latency (1.68 ± 0.07 ms vs. 1.62 ± 0.07 ms; $t=2.5$, $p=0.01$, $d=0.86$), indicating early auditory nerve involvement. Wave III latency was also delayed (3.9 ± 0.12 ms vs. 3.4 ± 0.11 ms; $t=5.1$, $p=0.01$, $d=4.34$), reflecting mid-brainstem differences. Wave V latency showed a marginal increase (5.77 ± 0.26 ms vs. 5.59 ± 0.18 ms; $t=2.9$, $p=0.05$, $d=0.80$). Interpeak latency analysis showed IPL I-III was longer in tinnitus participants (2.1 ± 0.06 ms vs. 2.02 ± 0.08 ms, $p=0.06$), while IPL III-V and I-V differences were not significant, suggesting preserved conduction in later brainstem

Table 3. Mean, standard deviation, and independent samples t-test results comparing combined (left and right ear) distortion product otoacoustic emission amplitudes between control and tinnitus groups

F2	Control group DPOAE in dB (mean±SD)	Tinnitus group DPOAE in dB (mean±SD)	T	p	Cohen's d
889	22.01±0.80	21.01±0.70	3.22	0.03	1.30
988	18.01±0.50	17.38±0.80	2.25	0.03	0.90
1481	14.67±0.80	13.27±1.00	2.60	0.01	1.50
2222	12.46±0.90	11.40±0.30	4.20	0.002	1.50
2963	10.18±0.80	9.20±0.40	3.70	0.001	1.50
4444	9.40±0.80	8.30±0.50	4.10	0.001	1.60
5714	7.82±0.90	5.80±0.40	7.20	0.001	2.90

DPOAE; distortion product otoacoustic emissions

Table 4. Mean, standard deviation, and independent samples t-test results comparing combined (left and right ear) transient evoked otoacoustic emissions amplitudes between control and tinnitus groups

Frequency Hz	Control group TEOAE in dB (mean±SD)	Tinnitus group TEOAE in dB (mean±SD)	T	P	Cohen's d
1000 Hz	16.20±1.00	14.8±1.10	3.50	0.001	1.30
2000 Hz	14.80±0.70	12.2±1.10	6.60	0.001	2.80
3000 Hz	9.80±0.90	8.0±0.50	6.80	0.001	2.40
4000 Hz	6.20±0.40	5.0±0.20	9.30	<0.001	3.70
5000 Hz	5.50±0.40	4.1±0.60	7.80	<0.001	2.70

TEOAE; transient evoked otoacoustic emissions

Table 5. Mean, standard deviation, and independent samples t-test results comparing combined (left and right ear) auditory brainstem responses components between control and tinnitus groups

ABR component	Control group latency in ms (mean±SD)	Tinnitus group latency in ms (mean±SD)	T	P	Cohen's d
Wave I	1.62±0.07	1.68±0.07	2.50	0.01	0.80
Wave III	3.40±0.11	3.90±0.12	5.10	0.01	4.30
Wave V	5.59±0.18	5.77±0.26	2.90	0.05	0.80
IPL I–III	2.02±0.08	2.10±0.06	30	0.06	-
IPL III–V	2.02±0.07	2.10±0.08	1.70	0.8	-
IPL I–V	4±0.13	4.10±0.14	1.60	0.1	-
ILD-V	0.12±0.04	0.13±0.07	1.70	0.09	-

stages. Interaural Latency Difference for wave V (ILD-V) was slightly elevated (0.13 ± 0.07 ms vs. 0.12 ± 0.04 ms, $p=0.09$), reflecting subtle binaural timing asymmetries. These results indicate early neural involvement with potential compensatory mechanisms in higher brainstem structures, as shown in Table 5.

Discussion

This study evaluated the clinical utility of a Tamil Speech-in-Noise (SIN) test within a multimodal framework to detect HHL in individuals with tinnitus and normal audiometric thresholds. Behavioral and electrophysiological findings provide converging evidence for subclinical auditory deficits in the tinnitus group, supporting the presence of HHL despite normal pure-tone sensitivity.

The Tamil SIN test revealed that participants with tinnitus required higher signal-to-noise ratios to achieve 50% keyword recognition compared to controls, indicating impaired auditory processing in complex acoustic environments. These individuals exhibited normal pure-tone thresholds, highlighting that standard audiometry fails to capture functionally relevant deficits. The SIN test's sensitivity to suprathreshold deficits aligns with literature linking cochlear synaptopathy to degraded speech-in-noise perception [19, 20].

These findings are consistent with earlier research in other Indian languages, such as Kannada and Malayalam, where native-language SIN tests detected auditory deficits despite normal audiograms [19, 20]. Similar deficits have been reported in Chinese-speaking tinnitus patients [21] and Western young adults with noise-induced tinnitus [22], reinforcing the cross-

linguistic universality of these suprathreshold auditory deficits. The validated Tamil SIN tool addresses a critical regional gap and supports culturally appropriate auditory assessment.

Combining behavioral and objective measures revealed subtle cochlear deficits. Distortion product otoacoustic emission amplitudes were reduced in the mid- to high-frequency ranges, and transient evoked otoacoustic emissions showed broad attenuation across 1.00–5.00 kHz, suggesting outer hair cell dysfunction. These abnormalities, which are not detected by standard audiometry, can impair spectral resolution and speech clarity, particularly in noisy listening environments. These findings are consistent with previous reports demonstrating reduced otoacoustic emission amplitudes in tinnitus patients with normal audiograms [23].

Participants reported mild to moderate tinnitus severity on the Tamil-translated Tinnitus Handicap Inventory (THI), confirming functional impact. Although THI scores did not correlate statistically with physiological measures, they reinforce real-world communication challenges. Together, these results support integrating native-language SIN testing with electrophysiological markers to improve detection of HHL and personalize tinnitus management.

Auditory Brainstem Response (ABR) analysis revealed significantly prolonged wave I and wave III latencies in the tinnitus group, while later components showed marginal trends toward delay. Wave I, originating from the distal auditory nerve, reflects synchronous auditory nerve activity and is considered the most direct marker of neural integrity. Reductions or delays in this wave indicate auditory nerve deafferentation and

synaptic loss consistent with cochlear synaptopathy [24]. Wave V latency showed a borderline difference, while IPL III-V and I-V remained unchanged, suggesting possible compensatory neural mechanisms in higher brainstem regions that maintain conduction times. Wave I latency therefore serves as a key electrophysiological signature of early neural involvement in tinnitus.

These findings highlight the importance of early intervention and auditory health monitoring. Conventional audiometry may fail to detect early neural or cochlear impairments, allowing subclinical damage to progress. A stepwise diagnostic pathway —Tamil SIN testing followed by OAE and ABR for patients with abnormal SIN results —offers a comprehensive, non-invasive approach for early detection. Training audiologists in language-specific SIN materials and ensuring access to electrophysiological testing can support integration into hearing conservation programs and tinnitus clinics, enabling earlier diagnosis, counseling, and monitoring.

Individuals with tinnitus and normal audiograms demonstrate hidden auditory dysfunction, evidenced by poorer SIN performance, reduced OAE amplitudes, and delayed early ABR waveforms. The Tamil SIN test, being culturally relevant and behaviorally sensitive, enhances clinical detection of suprathreshold deficits. Incorporating both behavioral and physiological measures into standard assessment protocols can improve early detection, guide intervention planning, and optimize patient outcomes.

The study was limited by a small sample size (n=15 per group), lack of tinnitus subtype differentiation, and absence of detailed profiling such as pitch, loudness, and qualitative descriptors. A formally validated Tamil Tinnitus Handicap Inventory (THI) was unavailable, and ear-specific data were averaged, preventing analysis of lateral differences in unilateral or asymmetric tinnitus. Future studies with larger, more diverse cohorts and detailed tinnitus characterization are warranted.

Conclusion

This study demonstrates that tinnitus patients with normal audiograms exhibit hidden auditory deficits, confirmed by impaired Speech-in-Noise (SIN) performance, reduced otoacoustic emissions amplitudes, and delayed auditory brainstem response latencies. The Tamil SIN test, in combination with electrophysiological measures, offers a sensitive approach for early detection. Incorporating such multimodal assessments can improve

clinical diagnosis, patient management, and hearing conservation strategies.

Ethical Considerations

Compliance with ethical guidelines

The study was approved by the Institutional Ethics Committee of Vinayaka Mission's Medical College and Hospital, Karaikal (Approval No. VMEC/2025/045). Written informed consent was obtained from all 30 participants (15 per group), and all procedures adhered to institutional ethical standards.

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Authors' contributions

AK: Study design, data collection, statistical analysis, interpretation of results, and drafting of the manuscript; AB: Supervision and critical revision of the manuscript.

Conflict of interest

The author declares no competing financial interests or personal relationships that could have influenced this study.

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