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Masseter Vestibular Evoked Myogenic Potentials (VEMP) as a Novel Diagnostic Tool in Multiple Sclerosis: A Comparative Study with Cervical VEMP

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ABSTRACT:

Background: Multiple sclerosis (MS) frequently involves subclinical brainstem lesions that may not be detected by conventional magnetic resonance imaging (MRI). Vestibular evoked myogenic potentials (VEMPs) provide a sensitive electrophysiological tool for assessing functional integrity of the brainstem. This study compared cervical VEMP (cVEMP) and masseter VEMP (mVEMP) in detecting brainstem dysfunction in patients with MS.

Methods: A cross-sectional comparative study was conducted on 30 female patients aged 18-60 years with relapsing–remitting MS (RRMS), diagnosed according to the 2017 McDonald criteria, and 30 healthy female controls aged 18–60 years. All participants underwent detailed audiological assessment, tympanometry, acoustic reflex testing, and both cVEMP and mVEMP recording using air-conducted stimuli. Latencies (P13, N23) and amplitudes were analyzed. Data were statistically evaluated using t-tests and receiver operating characteristic (ROC) analysis.

Results: No significant differences were found in pure-tone thresholds, speech reception thresholds, or tympanometry between groups ($p > 0.05$). MS patients showed significantly prolonged cVEMP P13 and N23 latencies ($p < 0.001$) and reduced amplitudes, indicating vestibulo-collic pathway dysfunction. mVEMP responses revealed more pronounced latency prolongation and amplitude reduction ($p < 0.001$), suggesting a slightly higher sensitivity for detecting trigemino-vestibular pathway involvement. ROC analysis showed AUC values of 0.78–0.88 for cVEMP and 0.81–0.89 for mVEMP, with mVEMP demonstrating higher sensitivity (up to 95%) and greater accuracy (73%). Abnormal VEMP findings significantly correlated with MRI-confirmed brainstem lesions ($p < 0.05$) as the distribution pattern particularly the periventricular and subcortical white matter involvement is classically characteristic of demyelinating disease.

Conclusion: Both cVEMP and mVEMP are sensitive measures of subclinical brainstem dysfunction in MS, with mVEMP offering slightly higher sensitivity and diagnostic accuracy. VEMP testing, particularly mVEMP, may serve as a valuable adjunct to MRI in early detection and monitoring of brainstem involvement in MS.

INTRODUCTION

Multiple sclerosis (MS) is a chronic inflammatory demyelinating disease of the central nervous system that frequently involves the brainstem. Brainstem lesions are often clinically silent, and conventional magnetic resonance imaging (MRI) may fail to detect subtle or early changes (1). This limitation emphasizes the need for sensitive and objective neurophysiological methods capable of detecting subclinical brainstem dysfunction.

Vestibular evoked myogenic potentials (VEMPs) are short-latency electromyographic responses generated by vestibular stimulation. They provide a non-invasive means of evaluating the functional integrity of specific vestibulo-brainstem pathways (2). The cervical VEMP (cVEMP), recorded from the ipsilateral sternocleidomastoid muscle, primarily assesses the saccule–inferior vestibular nerve–medial vestibulospinal tract pathway and serves as a reliable marker of lower brainstem integrity (3).

More recently, the masseter VEMP (mVEMP), recorded from the masseter muscle, has been introduced as a novel electrophysiological tool. It is believed to assess ipsilateral vestibulo-trigeminal projections, thereby offering complementary information regarding mid-to-upper brainstem function (4). Compared with cVEMP, mVEMP recording is technically easier in some populations, particularly in those who cannot maintain the neck muscle contraction required for cVEMP acquisition (5).

While cVEMP is a well-established clinical tool, mVEMP remains under investigation. Preliminary evidence suggests that mVEMP may be more sensitive to certain types of brainstem lesions, including those occurring in MS (6). Although recent systematic reviews by Subramanian and Siddaraju (2025), have summarized evidence regarding cVEMP, oVEMP, and mVEMP in multiple sclerosis, direct head-to-head comparisons of cVEMP and mVEMP within the same patient cohort remain limited.

Subclinical brainstem involvement is common in MS and can significantly impact disease progression and symptom burden (7). Identifying the most sensitive neurophysiological marker could enhance early detection and monitoring.

In this study, we aim to compare mVEMP and cVEMP in MS patients and healthy controls to evaluate their diagnostic sensitivity.

MATERIALS AND METHODS

Study Design and Setting

This was a cross-sectional comparative study conducted at the Audiology and Neurology Departments of Al-Zahraa University Hospital between July 2025 and October 2025. This study was designed and reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for cross-sectional observational research (8). The objective was to compare masseter vestibular evoked myogenic potentials (mVEMP) and cervical vestibular evoked myogenic potentials (cVEMP) in patients with MS and healthy controls to evaluate their relative diagnostic sensitivity in detecting subclinical brainstem dysfunction. The study protocol was approved by the Institutional Ethics Committee of Al-Zahraa University Hospital (no: 2025072829).

Participants

The study included two groups: a control group and a study group. The control group consisted of thirty healthy female participants aged between 18 and 60 years. All had normal hearing and no history suggestive of central nervous system pathology, systemic or local ear disease, acoustic or physical trauma, or neurological or musculoskeletal disorders.

The study group comprised thirty female patients. this study was an exploratory study investigating the diagnostic utility of mVEMP in MS, enrollment was based on the number of eligible patients presenting during the study period. The relatively small sample size may limit generalizability.

Multiple sclerosis has a well-known female predominance (female-to-male ratio ≈ 3:1). Recruitment was restricted to females to minimize potential sex-related variability in VEMP parameters and because the majority of eligible patients attending our clinic during the study period were female.

The age of the patients ranged between 18 and 60 years, they had been neurologically diagnosed with Relapsing–Remitting MS (RRMS) according to the 2017 McDonald criteria (9). Diagnosis was based on clinical history, neurological examination, and MRI findings. The patients were randomly selected from the outpatient Neurology Clinic at Al-Zahraa University Hospital. All included patients were free from other neurological disorders and had no history of ear infections, head trauma, or acute acoustic trauma.

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Equipment

Testing was carried out in a sound-treated room (locally made) using a two-channel diagnostic audiometer (Piano Plus) for audiometric evaluation, an Immittancemeter (MAICO MI44) for middle ear function assessment, and a Vestibular Evoked Myogenic Potential system (Interacoustics Eclipse/EP25) for recording both cervical and masseter VEMP responses.

Procedures

All participants underwent a detailed audiological, neurological, and medical history review, followed by otologic and neurological examinations. Brain MRI (1.5 Tesla) was performed for all patients in the MS group to confirm diagnosis and exclude other possible structural lesions.

Audiological evaluation included pure-tone audiometry, speech audiometry, and immittance testing. Pure-tone thresholds were obtained for air conduction across frequencies from 250 to 8000 Hz and for bone conduction across frequencies from 500 to 4000 Hz. Speech recognition thresholds (SRT) were determined using Arabic bisyllabic words (10), while word discrimination (WD) scores were obtained using Arabic monosyllabic phonetically balanced words (11). Immittance testing included tympanometry performed at pressures ranging from +200 to −400 mmH_2O to assess middle ear pressure and compliance, along with ipsilateral acoustic reflex threshold measurements elicited at 500, 1000, 2000, and 4000 Hz.

We followed our department protocol for the electrode montage and the recording parameters. Both cervical VEMP (cVEMP) and masseter VEMP (mVEMP) were recorded for each participant during the same session using air-conducted acoustic stimuli 500 tone burst at intensity 97 dB with repetition rate of 5 impulses per second, using insert ear phone.

Regarding the electrode montage, cVEMP surface active electrode was placed over the middle of ipsilateral sternocleidomastoid muscle, the reference electrode over the upper sternum and the ground electrode over the forehead. While for mVEMP active electrode was placed over the lower third of the masseter muscle, the reference (inverting) electrode over the zygomatic arch, and the ground electrode on the lower forehead. Participants were instructed to maintain a sustained contraction of the sternocleidomastoid muscle by turning their head toward the contralateral side, while for the masseter muscle by clenching their teeth firmly and maintain a steady jaw contraction throughout stimulus presentation. Muscle contraction was monitored visually to ensure adequate and stable activation throughout the recording. At least two reproducible waveforms were obtained from each participant to ensure response reliability. The primary VEMP parameters analyzed included peak latencies (p13 and n23 for cVEMP; P15 and N21 for mVEMP) and peak-to-peak amplitudes. Signal averaging and artifact rejection procedures were applied to ensure waveform accuracy. All tests were performed by the same experienced audiologist to minimize variability. Abnormality was determined based on prolonged latency values and/or reduced amplitudes relative to the normative ranges established from the healthy control group. latency > mean + 2 SD and/or amplitude < mean − 2 SD of controls.

Statistical Analysis

Data analysis was conducted using SPSS software (version 26 IBM Corp., Armonk, NY, USA). Quantitative variables were expressed as mean ± standard deviation (SD), and qualitative variables were presented as frequencies and percentages. Between-group comparisons were made using the independent-samples t-test for continuous data and the Chi-square test for categorical data. A p-value of less than 0.05 was considered statistically significant.

RESULTS

Pure-tone thresholds across frequencies (250–8000 Hz) showed no significant differences between the study and control groups ($p > 0.05$). Mean right-ear thresholds at 250 Hz were 11.0 ± 5.2 dB in controls and 11.8 ± 4.3 dB in MS patients ($p = 0.614$). All values remained within normal limits, confirming preserved cochlear function (**Supplementary Table S1**).

Speech reception thresholds were also comparable between groups (right ear: 9.5 ± 3.7 dB vs 10.5 ± 3.6 dB; $p = 0.450$), and all participants demonstrated excellent bilateral word discrimination (**Supplementary Table S2**). Tympanometry results were uniformly Type A for both ears in all subjects (**Supplementary Table S3**).

Contralateral acoustic reflex thresholds were significantly elevated in the MS group at multiple frequencies: right ear 500 Hz ($p = 0.047$), 1000 Hz ($p = 0.031$), 2000 Hz ($p = 0.011$), and 4000 Hz ($p = 0.011$); left ear 500 Hz ($p = 0.033$), 1000 Hz ($p =$

0.031), 2000 Hz (p = 0.014), and 4000 Hz (p = 0.023). Ipsilateral reflexes showed no significant difference (**Supplementary Table S4**).

Cervical VEMP (cVEMP) latencies were prolonged in the MS group (P13 = 15.67 ± 0.37 ms vs 13.45 ± 0.30 ms; p < 0.001; N23 = 25.57 ± 0.66 ms vs 23.80 ± 0.33 ms; p < 0.001). Amplitudes were significantly reduced (right = 19.11 ± 2.16 μV vs 21.47 ± 1.24 μV; p < 0.001), indicating vestibulo-collic pathway dysfunction (**Table 1**).

Masseter VEMP (mVEMP) findings showed even greater abnormalities with prolonged P13 (14.99 ± 0.52 ms vs 12.90 ± 0.13 ms; p <0.001) and N23 latencies (24.15 ± 0.45 ms vs 22.70 ± 0.14 ms; p < 0.001) alongside reduced amplitudes (20.83 ± 1.66 μV vs 27.15 ± 1.29 μV; p < 0.001), suggesting sensitivity for detecting brainstem involvement (**Table 2**).

ROC analysis confirmed good diagnostic performance for both modalities, with AUC values for cVEMP P13 ranging from 0.84–0.88 and for mVEMP P13 from 0.84–0.86. mVEMP demonstrated numerical higher sensitivity (up to 95%) and specificity (88%) compared with cVEMP (up to 90% and 75%), indicating better discriminative ability (**Table 3**, **Figure 1**, **Figure 2**).

MRI correlation revealed that patients with brainstem lesions were significantly more likely to exhibit abnormal cVEMP (p = 0.035) and mVEMP (p = 0.012) responses (**Table 4**). Predictive analysis showed mVEMP sensitivity = 68%, specificity = 87%, and accuracy = 73%, outperforming cVEMP (sensitivity = 64%, accuracy = 70%) for identifying brainstem pathology (**Table 5**).

Also, Multiple hyperintense focal lesions are visible across the provided MRI sequences (axial T2, coronal T2, FLAIR, and DWI/ADC-weighted layouts). **(Figure 3).**

The scans show multiple ovoid and well-defined high-signal lesions scattered within the periventricular white matter, centrum semiovale, and brainstem (including pontine regions). The lesions demonstrate high signal intensity on T2-weighted and FLAIR images. Some regions also show focal areas of restricted diffusion or bright foci depending on the slice level, which correlates directly with the clinical presentation of brainstem involvement impacting vestibular pathways such as those evaluated by cVEMP.

DISCUSSION

This study evaluated the diagnostic sensitivity of cervical vestibular-evoked myogenic potentials (cVEMP) and masseter vestibular-evoked myogenic potentials (mVEMP) for detecting subclinical brainstem dysfunction in MS. The findings indicate that both methods reliably reflect central vestibular-pathway involvement, with mVEMP showing slightly higher sensitivity and diagnostic accuracy (Table 2).

Recent literature supports and extends these results. For instance, a systematic review by Mansour et al. (2024) on VEMP in MS, emphasised that electrophysiological abnormalities such as prolonged latencies, reduced amplitudes and increased inter-aural asymmetry often occur even when brainstem lesions are not clearly visible on MRI (12). Meanwhile, a 2024 article by Nagarajan et al. described mVEMP as a promising adjunct test for brainstem lesions including MS (4).

A study by Thirusangu & Sinha (2023) established normative data for mVEMP in healthy individuals, highlighting its potential for detecting brainstem involvement in conditions such as MS (13). More recently, a retrospective study in 2023 on masseter VEMPs in MS patients found that mVEMP abnormalities were present in a greater proportion of patients compared with cVEMP (14). A methodological comparison by Nagarajan et al. (2024) found that 500 Hz narrow-band CE-chirps produced larger amplitudes and earlier latencies for mVEMP than clicks or tone bursts, which may enhance its diagnostic utility (4). Additional normative and comparative work (e.g., Gedik Toker et al., 2025) further supports the viability of mVEMP in brain-stem assessment (15).

A 2023 study by Uyaroglu et al. discussed stimulus-parameter effects on VEMPs (cVEMP, oVEMP) in healthy individuals, which underlines the importance of proper methods when applying these tests in MS (16). Another recent publication (Comacchio et al., 2025) in vestibular neuritis patients compared mVEMP and cVEMP and found that mVEMP may be more robust in certain contexts (though not MS-specific) (17).

In this study, the absence of peripheral auditory or middle-ear pathology (normal speech perception and tympanometric findings) underlines that the detected VEMP abnormalities can be interpreted as centrally mediated. The ability of electrophysiological tests (VEMPs) to reveal functional abnormalities even in the absence of MRI changes is corroborated by the recent review by Mansour et al. (2024) (12).

In our cohort, cVEMP responses showed prolonged P13/N23 latencies and reduced amplitudes, indicative of impaired conduction along the saccule–inferior vestibular nerve–medial vestibulospinal tract. These results mirror the pattern expected from demyelinating lesions affecting central vestibular pathways. The mVEMP recordings revealed latency prolongation and amplitude reduction, suggesting disruption of trigemino-vestibular circuits involving vestibular and trigeminal nuclei. The somewhat greater amplitude reduction observed in mVEMP may reflect the fact that mVEMP engages decussating and bilateral projections within the pons/midbrain, which may be more vulnerable in MS. Recent studies highlight that mVEMP may yield earlier or more robust abnormality detection than cVEMP in brain-stem conditions (4, 14).

From a diagnostic accuracy perspective, both modalities performed well, and mVEMP achieved slightly higher sensitivity and area under the curve (AUC) values in our analysis. This aligns with the 2025 study on mVEMP in MS showing higher abnormality rates for mVEMP than cVEMP (14). The slight higher abnormality of mVEMP likely stems from its assessment of trigemino-vestibular and trigemino-facial pathways circuits that may be more susceptible to MS-related demyelination than the primarily vestibulo-collic circuitry assessed by cVEMP.

The brain stem abnormal finding in MS patients was confirmed by using MRI scan in 22 patient (73.3%). Detailed lesion-volume measurements and anatomical subclassification of brainstem lesions were not consistently available in our retrospective MRI assessments and therefore were not included in the original analysis. The correlation in our dataset between MRI-confirmed brainstem lesions and abnormal VEMP responses supports the functional validity of these electrophysiologic measures. Importantly, some patients with no radiologic evidence of brainstem lesions still showed abnormal VEMP responses, indicating that VEMPs may detect microstructural dysfunction below the resolution of conventional MRI. This phenomenon is noted in the recent literature (12). The high specificity and positive predictive value of both VEMP techniques in our study confirm their clinical reliability, and the slightly higher sensitivity and accuracy of mVEMP highlight its value in early detection of brain-stem involvement.

LIMITATIONS

The relatively small sample size and only female participants may limit generalizability, larger studies are required to confirm any superiority of the mVEMP. future studies should evaluate correlations between VEMP findings and lesion location (pontine, midbrain, medullary) as well as lesion burden.

Medication effects, including disease-modifying therapies and corticosteroids, were not controlled and could have influenced electrophysiological responses. The cross-sectional design also limits assessment of temporal changes. Longitudinal studies are needed to determine whether VEMP abnormalities fluctuate with disease activity or improve with treatment.

CONCLUSION

Both cVEMP and mVEMP are sensitive indicators of subclinical brainstem dysfunction in MS, with mVEMP showing superior sensitivity and diagnostic accuracy. Preserved peripheral hearing and abnormal contralateral reflexes confirm that these measures specifically reflect central dysfunction. Incorporating VEMP testing into MS assessment, particularly mVEMP, may enable earlier identification of brainstem involvement even in cases with normal MRI findings.

Declarations

Ethics approval and consent to participate The study protocol was approved by the Institutional Ethics Committee of Al-Zahraa University Hospital (no: 2025072829). All participants were informed about the study objectives and procedures, and written informed consent was obtained from each participant prior to enrollment, in accordance with the Declaration of Helsinki.

Consent for publication

Not applicable. All data were anonymized before analysis, and no identifying information is included in this manuscript.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests related to this study.

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Authors' contributions Authors' contributions

All authors contributed to the conception and design of the study, data collection, analysis, and manuscript preparation. All authors have read and approved the final version of the manuscript.

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Supplementary Table S4. Ipsilateral and contralateral acoustic reflex thresholds in study and control groups

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Table 1. Cervical VEMP (cVEMP) in study vs control groups

cVEMP latencies were prolonged and amplitudes reduced in MS patients.

Measure	Ear	Study group Mean ± SD	Min–Max	Control group Mean ± SD	Min–Max	t-test	p-value
P13 latency (ms)	Right	15.67 ± 0.37	15.00–16.80	13.45 ± 0.30	12.95–13.95	25.26	0.001*
	Left	15.83 ± 0.64	14.80–17.75	13.45 ± 0.30	13.00–13.90	18.56	0.001*
N23 latency (ms)	Right	25.57 ± 0.66	24.00–27.22	23.80 ± 0.33	23.04–24.37	12.94	0.001*
	Left	25.83 ± 0.44	25.17–26.82	23.92 ± 0.42	23.00–24.96	17.01	0.001*
P13–N23 amplitude (μV)	Right	19.11 ± 2.16	15.00–23.25	21.47 ± 1.24	19.13–23.34	−5.17	0.001*
	Left	18.74 ± 2.31	15.41–23.27	21.45 ± 1.19	18.63–23.73	−5.69	0.001*

*Values are presented as mean ± standard deviation (SD). P13 and N23 latencies are expressed in milliseconds (ms); amplitudes in microvolts (μV). Asterisk () denotes statistical significance at $p < 0.05$. Prolonged latencies and reduced amplitudes indicate vestibulo-collic pathway dysfunction.**

Table 2. Masseter VEMP (mVEMP) in study vs control groups

mVEMP latencies were prolonged and amplitudes reduced in MS patients.

Measure	Ear	Study group Mean ± SD	Min–Max	Control group Mean ± SD	Min–Max	t-test	p-value
P13 latency (ms)	Right	14.99 ± 0.52	13.90–16.00	12.90 ± 0.13	12.70–13.10	21.09	0.001*
	Left	15.25 ± 0.53	14.00–16.34	13.12 ± 0.15	12.90–13.40	20.81	0.001*
N23 latency (ms)	Right	24.15 ± 0.45	23.10–25.30	22.70 ± 0.14	22.50–22.90	16.60	0.001*
	Left	24.06 ± 0.33	22.90–24.40	22.73 ± 0.13	22.50–22.90	20.10	0.001*
P13–N23 amplitude (μV)	Right	20.83 ± 1.66	16.64–23.46	27.15 ± 1.29	25.05–29.26	−16.43	0.001*
	Left	20.82 ± 1.56	17.46–23.85	27.60 ± 1.56	23.41–29.88	−16.73	0.001*

*Values are mean ± SD. P13 and N23 latencies are expressed in milliseconds (ms); amplitudes in microvolts (μV). Asterisk () denotes $p < 0.05$. Latency prolongation and amplitude reduction reflect trigemino-vestibular pathway dysfunction.**

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Table 3. ROC analysis for cVEMP and mVEMP latencies

Area under the curve (AUC), optimal cut-offs, sensitivity, and specificity.

Test	Ear	AUC	Cut-off	Sensitivity	Specificity
cVEMP P13	Right	0.84	> 15.52	0.77	0.75
cVEMP P13	Left	0.88	> 15.47	0.90	0.75
cVEMP N23	Right	0.78	> 25.29	0.72	0.75
cVEMP N23	Left	0.85	> 25.64	0.81	0.88
mVEMP P13	Right	0.84	> 14.80	0.90	0.75
mVEMP P13	Left	0.86	> 15.12	0.95	0.88
mVEMP N23	Right	0.89	> 23.99	0.95	0.75
mVEMP N23	Left	0.81	> 24.05	0.77	0.75

AUC = area under the curve. Cut-off values determined by Youden's index. Sensitivity and specificity values represent optimal diagnostic thresholds. All p-values < 0.05 were considered significant.

Table 4. Association of MRI-confirmed brainstem lesions with VEMP outcomes (study group, n=30)

MRI brainstem lesion	cVEMP Normal	cVEMP Abnormal	p-value	mVEMP Normal	mVEMP Abnormal	p-value
Yes (n=22)	8 (36%)	14 (64%)	0.035*	7 (32.8%)	15 (68.2%)	0.012*
No (n=8)	7 (87.5%)	1 (12.5%)		7 (87.5%)	1 (12.5%)	

*Data are presented as number (percentage). MRI = magnetic resonance imaging. Asterisk () denotes statistically significant association (p < 0.05) between MRI-confirmed brainstem lesions and VEMP abnormalities.**

Table 5. Prediction of brainstem lesions by cVEMP and mVEMP (study group)

Test	TP	TN	FP	FN	Sensitivity	Specificity	PPV	NPV	Accuracy
cVEMP	14	7	1	8	64%	87%	93%	46%	70%
mVEMP	15	7	1	7	68%	87%	94%	50%	73%

TP = true positive; TN = true negative; FP = false positive; FN = false negative; PPV = positive predictive value; NPV = negative predictive value. Sensitivity, specificity, and accuracy are expressed as percentages (%).

Supplementary Table S1. Pure-tone air-conduction thresholds (dB HL) for right and left ears in study and control groups

Frequency (Hz)	Ear	Control Group Mean ± SD	Study Group Mean ± SD	*p*-value
250	Right	11.0 ± 5.2	11.8 ± 4.3	0.614
	Left	10.5 ± 5.0	13.2 ± 3.6	0.073
500	Right	11.5 ± 4.7	12.0 ± 4.1	0.748
	Left	10.0 ± 4.1	11.2 ± 3.9	0.420
1000	Right	12.5 ± 5.4	11.5 ± 4.9	0.591

	Left	11.0 ± 5.2	11.0 ± 4.8	1.000
2000	Right	11.5 ± 4.7	9.7 ± 3.9	0.232
	Left	11.0 ± 4.6	11.2 ± 3.9	0.911
4000	Right	11.0 ± 5.7	11.7 ± 5.1	0.731
	Left	11.5 ± 4.7	11.8 ± 4.4	0.841
8000	Right	11.5 ± 4.7	12.7 ± 4.1	0.458
	Left	11.5 ± 5.8	13.2 ± 5.8	0.436

Data are mean ± SD. No significant differences were observed across frequencies ($p > 0.05$). dB HL = decibel hearing level.

Supplementary Table S2. Speech Reception Threshold (SRT) comparison between study and control groups**

Ear	Control Group Mean ± SD	Study Group Mean ± SD	*p*-value
Right	9.5 ± 3.7	10.5 ± 3.6	0.450
Left	9.5 ± 3.7	10.7 ± 3.9	0.410

Values are mean ± SD. SRT = speech reception threshold (dB HL). All participants demonstrated normal speech discrimination scores.

Supplementary Table S2. Tympanogram results for study and control groups

Ear	Tympanogram Type	Control Group (n=30)	Study Group (n=30)
Right	A	30 (100%)	30 (100%)
Left	A	30 (100%)	30 (100%)

All participants exhibited bilateral Type A tympanograms, consistent with normal middle ear function.

Supplementary Table S4. Ipsill acoustic reflex thresholds (dB HL) in study and control groups

Reflex	Frequency (Hz)	Control Mean ± SD	Study Mean ± SD	*t*-value	*p*-value
Right ipsilateral	1000	90.67 ± 4.10	90.00 ± 6.95	0.453	0.652
Right ipsilateral	2000	90.67 ± 3.14	91.67 ± 8.24	0.621	0.537
Right contralateral	500	91.00 ± 3.32	93.10 ± 5.90	1.891	0.047*
Right contralateral	1000	92.00 ± 3.11	94.23 ± 5.66	1.891	0.031*
Right contralateral	2000	92.67 ± 2.54	95.45 ± 5.96	2.350	0.011*
Right contralateral	4000	95.00 ± 3.71	98.18 ± 6.46	2.338	0.011*
Left ipsilateral	1000	92.67 ± 4.50	92.00 ± 7.61	0.413	0.681
Left ipsilateral	2000	92.33 ± 5.83	92.67 ± 7.04	0.200	0.842
Left contralateral	500	92.00 ± 3.62	94.44 ± 6.19	1.863	0.033*
Left contralateral	1000	93.00 ± 3.11	95.30 ± 5.88	1.893	0.031*
Left contralateral	2000	94.67 ± 3.46	97.48 ± 5.92	2.244	0.014*
Left contralateral	4000	92.33 ± 5.83	96.39 ± 9.28	2.029	0.023*

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Values are mean ± SD in decibel hearing level (dB HL). Asterisk () denotes significant difference at $p < 0.05$. Elevated contralateral reflex thresholds indicate early brainstem involvement.*

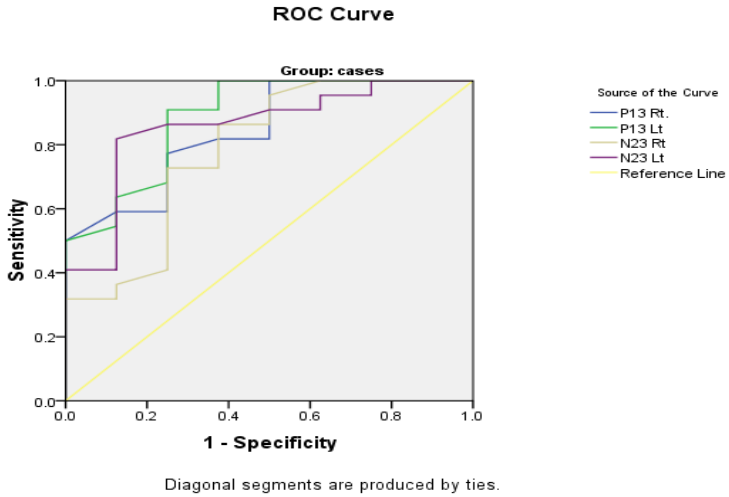

Figure 1. Receiver Operating Characteristic [ROC] Curve for the C-VEMP test P13 and N23 Latencies of Left and Right Ear.

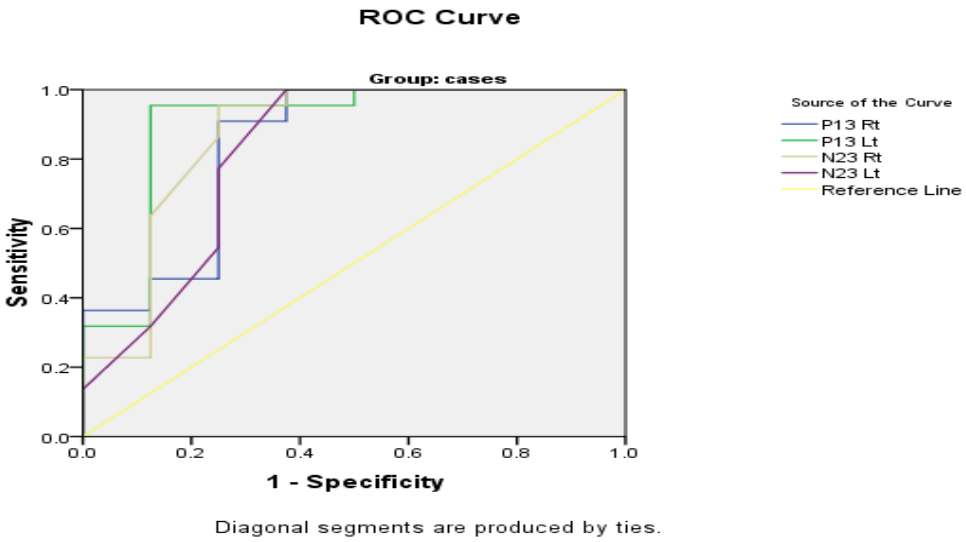

Figure 2. Receiver Operating Characteristic [ROC] Curve for the M-VEMP test P13 and N23 Latencies of Left and Right Ear.

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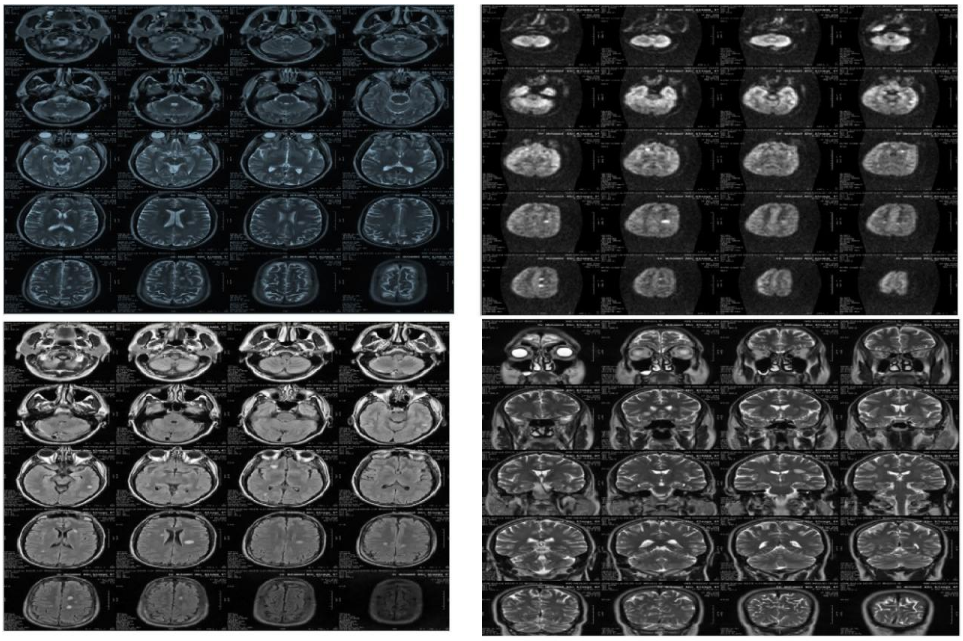

Figure 3: Multiple bilateral periventricular oval shaped foci and patches of abnormal signal intensity are seen scattered in the deep white matter being inconspicuous in T1WI and bright in T2 and FLAIR WIs. In addition, show variable degree of diffusion restriction at DWI. They exert no mass effect and are not surrounded by edema.