RESEARCH PAPER

Postural Control and Balance Confidence in Adults with Hearing Loss: Influence of Severity of Hearing Loss and Hearing Aid Use

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Abstract
Background: Age-related hearing loss and vestibular dysfunction are both highly prevalent in older adults and are associated with balance deficits and increased fall risk. While previous studies have reported a general association between hearing loss and vestibular impairment, limited evidence exists on how varying degrees of hearing loss relate to specific otolith organ dysfunction. The present study aimed to evaluate otolith function in older adults with different degrees of sensorineural hearing loss (SNHL) using cervical vestibular evoked myogenic potentials (cVEMP) and ocular vestibular evoked myogenic potentials (oVEMP).
Methods: A cross-sectional study was conducted on 40 participants aged 50–70 years. Group I included 10 individuals with normal hearing, while Group II comprised 30 individuals with bilateral SNHL, subdivided into mild, moderate, and moderately severe groups based on pure-tone averages. cVEMP and oVEMP responses were recorded at 500, 1000, and 2000 Hz. Latency and amplitude parameters were analyzed using ANOVA and post hoc tests.
Results: Results revealed reduced or absent VEMP responses in individuals with hearing loss compared to those with normal hearing. A significant reduction in amplitude was observed with increasing severity of hearing loss for both cVEMP and oVEMP across frequencies ($p < 0.05$). Prolonged P13 latency in cVEMP was noted in moderately severe SNHL, whereas other latency measures remained largely unaffected. Logistic regression indicated a moderate association between hearing loss severity and VEMP abnormalities.
Conclusion: These findings suggest a progressive decline in otolith organ function with increasing severity of hearing loss, indicating possible shared degenerative mechanisms affecting the cochlea and vestibular system. VEMP measures may serve as valuable clinical tools for early identification of vestibular involvement in individuals with SNHL.

Keywords: Age-related hearing loss, cVEMP, oVEMP
How to cite this article: Nikita N, Vanaja CS. Postural Control and Balance Confidence in Adults with Hearing Loss: Influence of Severity of Hearing Loss and Hearing Aid Use. Int J Drug Deliv Technol. 2026;16(41s): 855-861. DOI: 10.25258/ijddt.16.41s.90

Introduction:
Hearing loss and vestibular dysfunction are prevalent among older adults. While hearing loss affects approximately 25% of individuals over 50 years old, [1] and nearly 50% of those over 65 years old [2], vestibular dysfunction is reported in 35.4% of adults over 40 years old [3], and in 65% of those over 60 years old [4] .Research increasingly points to a connection between hearing loss, especially moderate to severe, and altered vestibular responses contributing to balance deficits and heightened fall risk [5,6]. Although prior research establishes a general link between hearing loss and vestibular dysfunction, there is a gap in the existing literature regarding how specific degrees of hearing loss (e.g., mild, moderate, or moderately severe) correlate with distinct patterns of otolith dysfunction in older adults. Understanding this interplay, especially in older adults with mild to moderately severe hearing loss, is crucial.
This study aimed to investigate otolith organ function in older adults, with varying degrees of hearing loss, using cervical vestibular evoked myogenic potentials (cVEMP) and ocular vestibular evoked myogenic potentials (oVEMP) tests. These tests assess the otolith organs' roles in detecting linear acceleration and head tilt, which are essential for maintaining postural stability [7 8]. By analyzing cVEMP and oVEMP outcomes, we can gain detailed insights into whether age-related hearing loss corresponds with specific patterns of otolith dysfunction, potentially reflecting shared degenerative processes in the inner ear.

Material and method
This cross-sectional study recruited 40 participants, aged 50-70 years, via purposive sampling. Group I comprised

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10 older adults with normal hearing. Group II comprised 30 older adults with bilateral symmetrical sensorineural hearing loss. Group II was further divided into three subgroups based on the average of pure tone thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz (PTA). Group II-A included ten older adults with mild hearing loss (26 to 40 dB HL PTA), Group II-B included ten older adults with moderate hearing loss (41 to 55 dB HL PTA), and Group II-C consisted of ten older adults with moderately severe hearing loss (56 to 70 dB HL PTA). Exclusion criteria included conductive hearing loss, retrocochlear pathology, cognitive/neurological impairments, uncontrolled systemic conditions, uncorrected visual problems, postural hypotension, or psychiatric disorders. Ethical approval was obtained (name removed for review), and informed consent was obtained from all participants.

Procedure

Participants underwent comprehensive case history, pure-tone audiometry, and immittance evaluation to assess hearing status and rule out conductive pathologies. cVEMP and oVEMP were recorded using an Eclipse EP25 device in an acoustically treated room, maintaining electrode impedance below 5 kΩ. Electromyography (EMG) levels were continuously monitored during the test to ensure a minimum muscle tension of 50 µV.

For recording cVEMP, active, reference, and ground electrodes were placed on the sternocleidomastoid (SCM) muscle, upper sternum, and forehead, respectively. SCM activation involved head rotation, sideways gaze, and chin tuck. Acoustic stimuli (500, 1000, 2000 Hz tone bursts of rarefaction polarity) were presented monaurally at 95 dBnHL, with a 5.1/s repetition rate. Each trial averaged 200 stimuli. EMG signals were filtered (30–1500 Hz), amplified (x5000), and analyzed in a −20 to 80 ms window for P13 and N23 latencies and P1-N1 amplitude. Two trials ensured waveform reproducibility for each frequency. For oVEMP, active, reference, and ground electrodes were placed 1 cm below the lower eyelid, 1.5 cm below the lower eyelid, and on the forehead, respectively. Participants gazed 20° upward to activate the inferior oblique muscle. Stimuli (500, 1000, 2000 Hz tone bursts, rarefaction polarity) were delivered to the contralateral ear at 95 dB nHL, with a 5.1/s repetition rate. EMG signals were filtered (1–1000 Hz), amplified (x5000), and averaged over 200 stimuli. Two runs were recorded at each frequency. The waveforms were analyzed to record latencies of N10 and P15 as well as peak-to-peak amplitude.

Analysis

Statistical analysis was performed using Jeffreys's Amazing Statistics Program (JASP) version 0.19.2. The Shapiro-Wilk test confirmed data normality. Descriptive statistics (mean, standard deviation) were computed. ANOVA was used for statistical comparisons of VEMP parameters across the three groups, followed by Tukey's post hoc analysis to identify significant differences between groups.

Results

The mean age for Group I was 60.2±3.1 years, for Group II-A was 59.0±3.9 years, for Group II-B it was 60.6±3.7 years, and for Group II-C, the mean age was 62.8±3.5 years. Group I consisted of 6 females and 4 males, Group II-A had 5 females and 5 males, Group II-B comprised 4 females and 6 males, and Group II-C included 3 females and 7 males. cVEMP and oVEMP responses could be recorded from all 10 older adults with normal hearing, whereas responses were either affected or absent in older adults with hearing loss, as shown in Figs 1 and 2 for cVEMP and oVEMP, respectively. Table 1 and 2 shows the descriptive statistics for latency and amplitude across three groups for cVEMP and oVEMP, respectively. It can be observed from the tables that the amplitude of both cVEMP and oVEMP decreased with the severity of hearing loss.

Fig1. Abnormal cVEMP responses across groups

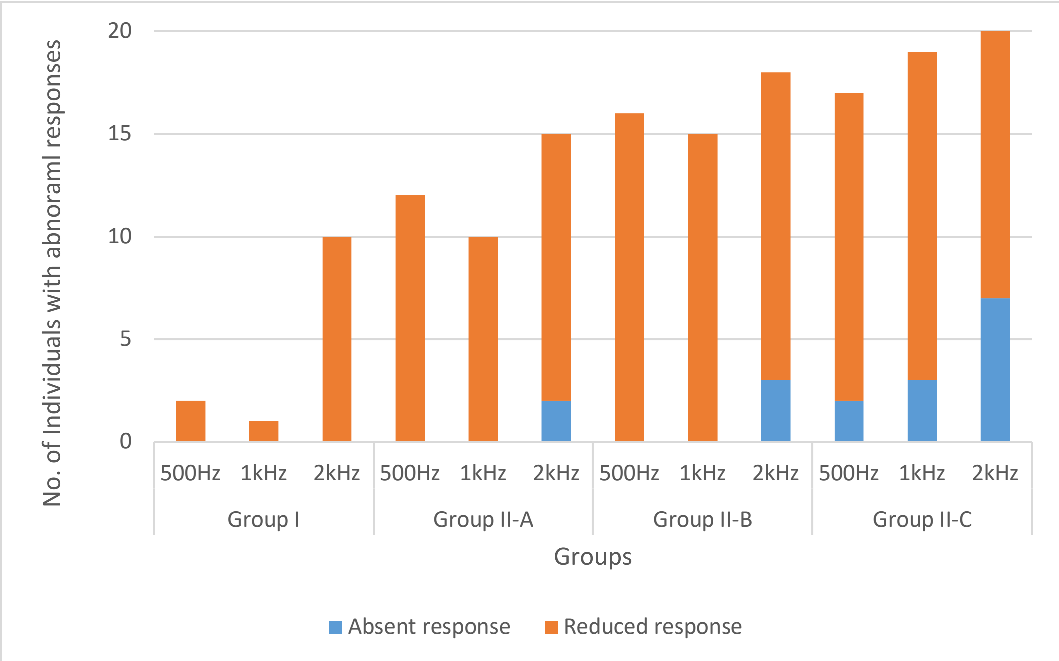
No. of Individuals with abnoraml responses
20
15
10
5
0
500Hz
1kHz
2kHz
Group I
Group II-A
Group II-B
Group II-C
Groups
Absent response
Reduced response

Fig 2. Abnormal cVEMP responses across groups

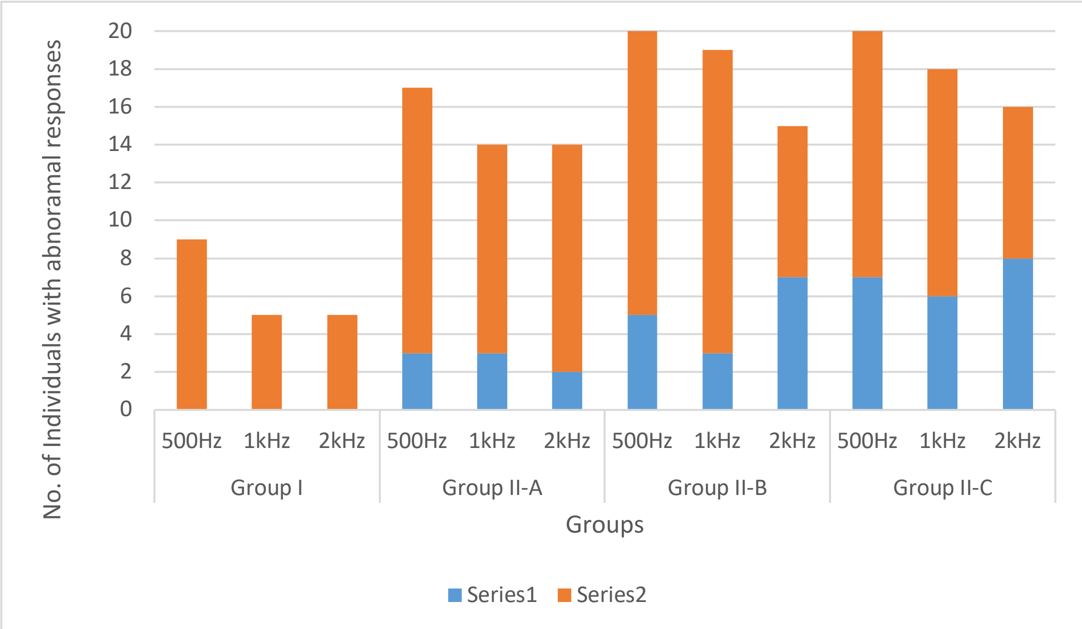

Table 1: Latency (in msec) of peaks of cVEMP and oVEMP across frequencies

Measure	Ear	Variable	Group	500 Hz	1000 Hz	2000 Hz
				Mean (*SD*)	*Mean* (*SD*)	*Mean* (*SD*)
cVEMP	Right	P13 Latency	Group I	13.93 (1.80)	13.40 (1.20)	12.25 (1.00)
			Group II-A	15.63 (1.70)	14.33 (1.00)	13.20 (0.10)
			Group II-B	15.46 (2.30)	14.29 (0.80)	13.00 (1.90)
			Group II-C	15.77 (1.70)	15.16 (1.50)	15.78 (2.80)
		N23 Latency	Group I	22.06 (2.20)	21.00 (1.80)	19.90 (2.20)
			Group II-A	23.03 (0.09)	20.43 (1.90)	19.43 (2.00)
			Group II-B	23.83 (2.40)	21.81 (1.60)	19.75 (3.90)
			Group II-C	23.96 (3.30)	22.16 (2.40)	21.78 (2.60)
	Left	P13 Latency	Group I	14.30 (1.70)	13.73 (0.90)	12.83 (1.40)
			Group II-A	16.13 (1.90)	13.54 (0.70)	12.75 (0.10)
			Group II-B	16.00 (1.60)	13.73 (1.70)	13.03 (1.30)
			Group II-C	16.34 (1.80)	14.60 (1.70)	15.19 (3.20)
		N23 Latency	Group I	22.60 (2.10)	20.76 (2.10)	20.23 (2.50)
			Group II-A	23.23 (2.10)	20.63 (0.10)	12.75 (0.10)
			Group II-B	23.70 (1.80)	20.77 (2.90)	13.03 (1.30)
			Group II-C	23.90 (1.50)	21.61 (1.90)	15.19 (3.20)
oVEMP	Right	P15 Latency	Group I	16.53 (2.40)	15.43 (1.90)	14.33 (0.60)
			Group II-A	16.13 (1.30)	15.08 (1.60)	15.26 (1.70)
			Group II-B	16.12 (2.00)	15.30 (1.30)	15.18 (1.20)
			Group II-C	18.39 (2.30)	15.66 (2.30)	16.43 (2.10)
		N10 Latency	Group I	12.33 (1.90)	11.26 (1.20)	10.46 (1.90)
			Group II-A	12.70 (1.40)	11.24 (1.70)	11.08 (1.50)
			Group II-B	12.67 (4.50)	12.22 (3.90)	11.76 (1.20)
			Group II-C	14.61 (2.50)	12.00 (2.70)	11.23 (1.60)
	Left	P15 Latency	Group I	16.50 (2.40)	15.23 (2.10)	14.26 (1.40)
			Group II-A	16.67 (1.70)	15.83 (2.10)	15.20 (1.80)
			Group II-B	16.39 (2.10)	15.95 (1.40)	15.18 (1.20)
			Group II-C	18.81 (1.50)	17.71 (3.40)	16.42 (4.20)
		N10 Latency	Group I	12.47 (2.10)	11.43 (1.60)	10.48 (1.30)
			Group II-A	13.57 (2.10)	11.16 (1.70)	10.35 (2.10)
			Group II-B	14.09 (3.90)	12.46 (4.00)	10.89 (1.60)
			Group II-C	14.14 (3.40)	13.14 (1.80)	10.46 (1.10)

Table 2: Amplitude (µV) of cVEMP and oVEMP across frequencies

Measure	Ear	Group	500 Hz	1000 Hza	2000 Hz
			Mean (*SD*)	*Mean* (*SD*)	*Mean*(*SD*)
cVEMP	Right	Group I	1.17 (0.50)	1.35 (0.38)	0.65 (0.33)
		Group II-A	0.63 (0.09)	0.71 (0.20)	0.40 (0.50)
		Group II-B	0.36 (0.07)	0.45 (0.20)	0.28 (0.20)
		Group II-C	0.31 (0.07)	0.45 (0.40)	0.27 (0.20)
	Left	Group I	1.07 (0.48)	1.21 (0.30)	0.70 (0.41)
		Group II-A	0.59 (0.40)	0.72 (0.40)	0.72 (0.40)
		Group II-B	0.45 (0.20)	0.52 (0.40)	0.51 (0.40)
		Group II-C	0.31 (0.10)	0.45 (0.30)	0.45 (0.30)
oVEMP	Right	Group I	0.63 (0.60)	0.67 (0.39)	0.56 (0.13)
		Group II-A	0.30 (0.30)	0.48 (0.21)	0.32 (0.16)
		Group II-B	0.19 (0.07)	0.21 (0.13)	0.22 (0.10)
		Group II-C	0.18 (0.08)	0.33 (0.25)	0.22 (0.09)
	Left	Group I	0.51 (0.15)	0.61 (0.32)	0.55 (0.15)
		Group II-A	0.28 (0.18)	0.45 (0.23)	0.31 (0.13)
		Group II-B	0.12 (0.06)	0.27 (0.10)	0.23 (0.11)
		Group II-C	0.17 (0.11)	0.31 (0.19)	0.20 (0.08)

Table 3: ANOVA test results across frequencies for cVEMP and oVEMP

Measure	Ear	Variable	500 Hz		1000 Hz		2000 Hz	
			F (df)	*p*	*F* (df)	*p*	*F* (df)	*p*
cVEMP	Right	P13 Latency	3.53 (3, 35)	0.02	3.21 (3, 33)	0.03	4.49 (3, 30)	0.01
		N23 Latency	1.30 (3, 35)	0.28	1.46 (3, 33)	0.24	1.47 (3, 30)	0.24
		Amplitude	3.32 (3, 35)	< .001	7.91 (3, 33)	< .001	3.48 (3, 30)	0.02
	Left	P13 Latency	0.87 (3, 35)	0.03	1.12 (3, 35)	0.04	1.60 (3, 30)	0.04
		N23 Latency	0.23 (3, 35)	0.35	0.38 (3, 35)	0.54	3.26 (3, 30)	0.08
		Amplitude	3.44 (3, 35)	0.02	5.37 (3, 35)	0.04	0.22 (3, 30)	0.04
oVEMP	Right	P15 Latency	1.89 (3, 29)	0.15	1.00 (3, 30)	0.40	1.02 (3, 27)	0.40
		N10 Latency	1.41 (3, 29)	0.26	0.41 (3, 30)	0.75	0.38 (3, 27)	0.77
		Amplitude	3.12 (3, 29)	0.03	5.30 (3, 30)	0.005	3.05 (3, 27)	0.04
	Left	P15 Latency	0.36 (3, 27)	0.78	1.04 (3, 30)	0.39	1.52 (3, 25)	0.24
		N10 Latency	0.63 (3, 27)	0.60	0.89 (3, 30)	0.46	0.52 (3, 25)	0.68
		Amplitude	4.56 (3, 27)	0.02	5.08 (3, 30)	0.006	4.30 (3, 25)	0.01

ANOVA was done to investigate the effect of hearing loss on cVEMP and oVEMP across three groups. As presented in Table 3, a statistically significant effect of hearing loss was observed for the P1-N1 amplitude and P13 latency of cVEMP at 500 Hz, 1000 Hz, and 2000 Hz in both ears ($p < 0.05$). Post hoc analyses revealed that in both ears, the P1-N1 amplitude of Group I was significantly different from those of Groups II-A, II-B, and II-C at 500 and 1000 Hz. Further, there was a significant difference between Group II-A and Group II-C, in both ears, at 500 Hz and 1000 Hz. At 2000 Hz, the amplitude of Group I differed significantly from that of Groups II-B and II-C in both ears. For P13 latency, significant differences were noted between Group I and Group II-C at 500 Hz, 1000 Hz, and 2000 Hz in both ears. For oVEMP, a statistically significant effect of hearing loss was observed for the P1-N1 amplitude at 500 Hz, 1000 Hz, and 2000 Hz in both ears ($p < 0.05$). Post hoc comparisons indicated that the amplitude of P1-N1 of Group I differed significantly from those of Groups II-A, II-B, and II-C at 500 Hz and 1000 Hz in both ears. Also, the amplitude of P1-N1 of Group I differed significantly from those of Groups II-B and II-C at 2000 Hz in both ears. Logistic regression analysis was conducted to evaluate whether the absence or abnormalities of cVEMP and oVEMP were dependent on the pure tone thresholds. Regression analysis was carried out separately for 500, 1000 and 2000 Hz. The Nagelkerke R^2 values were 0.361 at 500 Hz, 0.405 at 1000 Hz, and 0.463 at 2000 Hz for cVEMP, while the Nagelkerke R^2 values were 0.205 at 500 Hz, 0.512 at 1000 Hz, and 0.422 at 2000 Hz for oVEMP.

Discussion

This study investigated otolith organ function, as measured by cVEMP and oVEMP, in older adults with varying severity of hearing loss compared to those with normal hearing. It was observed that the response rate was affected in older adults with hearing loss as compared to older adults with normal hearing. This observation aligns with previous research, which also reported similar reductions in older adults with moderate to profound hearing loss [9, 10, 12, 13]. The current study showed that the amplitude of VEMP is affected even when there is a mild hearing loss.

Furthermore, the current study consistently demonstrated that the reduction in VEMP amplitudes in older adults with hearing loss was more pronounced as the severity of SNHL increased from mild to moderately severe. At 500 Hz and 1000 Hz, all groups with hearing loss had significantly reduced amplitude when compared to persons with normal hearing, and there was a significant difference in the amplitude of responses obtained for participants with mild and moderately severe hearing loss. At 2000 Hz, only those with moderate and moderately severe hearing loss had significantly reduced amplitude. Interestingly, the amplitude differences between the moderate and moderately severe SNHL groups were minimal for both cVEMP and oVEMP, suggesting a potential plateau effect. This progressive decline in VEMP amplitudes strongly suggests that the otolith organs (saccule and utricle), which generate these potentials, may undergo degenerative changes that parallel those observed in the auditory system.

These results are crucial findings indicating a probable shared physiological deterioration or an interconnected susceptibility of the auditory and vestibular systems to age-related or SNHL-associated degeneration [11.] .These shared degenerative processes in the inner ear are probably driven by the close anatomical and physiological relationship between the cochlea and vestibular organs. The anatomical proximity of the cochlea and vestibular organs makes both systems susceptible to similar pathological changes, such as those caused by ageing, ototoxicity, or other factors contributing to hearing loss[14].

Also, a significant difference in the P13 latency for cVEMP was observed between older adults with normal hearing and those with moderately severe SNHL, particularly at 500 Hz, 1000 Hz, and 2000 Hz in both ears. Similar to these results, earlier studies indicate that higher degrees of hearing loss are associated with absent cVEMP responses, prolonged latencies, and reduced amplitudes [12 15]. This finding suggests that moderately severe SNHL may affect the timing of the saccular reflex pathway, potentially due to degenerative changes in the vestibular nerve or otolith organ.

Conversely, no significant changes were found in the latency of the P1-N1 peaks for oVEMP or the N1 peak for cVEMP across any of the studied groups. Our findings align with previous research that suggests latency remains unaffected despite the reduction in amplitude [13 17]. Similarly, previous studies have reported that the latency of cVEMP and oVEMP responses remained stable even when the amplitude decreased with increasing hearing loss [12]. This could imply that while the vestibular response becomes less pronounced as hearing loss worsens, the conduction time along the vestibular pathways may not be significantly altered in the range of SNHL severity observed in our study.

Logistic regression analysis showed moderate explanatory power for cVEMP, suggesting that the severity of hearing loss accounts for 36.1 to 46.3% of variance across 500–2000 Hz, with stronger associations at higher frequencies. For oVEMP, severity of hearing loss accounted for 20.5–51.2% of the variance in responses, with a stronger association at 1000Hz. Earlier studies on adults have shown that in persons with sensorineural hearing loss, the amplitude/presence of VEMP is not dependent on the severity of hearing loss in adults[16]. Thus, the results of the present study, in conjunction with these earlier reports, suggest that there are corresponding age-related changes in the vestibular system in persons with age-related hearing loss.

Unlike previous studies that often grouped SNHL broadly or focused on single frequencies, this study provided a detailed multi-frequency (500 Hz, 1000 Hz, 2000 Hz) and severity-stratified approach, which offered a more detailed characterization of otolith dysfunction, revealing trends such as the plateau effect in amplitude reduction at higher SNHL severities. One of the limitations of this study is the relatively small sample size, which may affect the generalizability of the findings. Future studies could include a larger cohort and explore additional vestibular tests, such as video head impulse testing, to provide a more comprehensive evaluation of the vestibular system in individuals with SNHL and adopt longitudinal designs to track SNHL and vestibular changes over time.

Conclusions

Our study reveals that VEMP amplitude is affected in older adults with hearing loss. Furthermore, the findings indicate the progressive decline in P1-N1 amplitude as hearing loss severity increased from mild to moderately severe. Notably, a delayed P13 latency in cVEMP was observed in individuals with moderately severe SNHL, while N23 latency for cVEMP and N10-P15 latencies for oVEMP remained unaffected across the groups. This suggests that while the amplitude of the vestibular response may be affected by hearing loss, the timing of these responses largely remains consistent. These findings underscore the potential of cVEMP and oVEMP as valuable tools for assessing otolith organ dysfunction in SNHL. Further research is essential to explore the clinical implications of these observations for managing patients with cochleovestibular disorders.

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