Research Article

Cervical Vestibular Evoked Myogenic Potentials in Older Adults: Comparison of Amplitude and Frequency Tuning Across Different Severity of Hearing Loss

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Highlights

- cVEMP amplitude reduced with increasing severity of hearing loss
- Frequency tuning shift to 1000 Hz was observed in older adults with hearing loss
- Saccular and cochlear function decline in parallel in older adults with hearing loss

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ABSTRACT

Background and Aim: Hearing loss and vestibular dysfunction frequently co-occur in older adults, affecting balance and mobility. Changes in the vestibular system can alter cervical vestibular myogenic potentials. This study aimed to investigate the amplitude and frequency tuning characteristics of cervical Vestibular Evoked Myogenic Potentials (cVEMP) across different degrees of hearing loss in older adults.

Methods: A cross-sectional study was conducted with 30 young adults with normal hearing and 30 older adults (50–70 years) with bilateral sensorineural hearing loss, categorized into mild, moderate and moderately severe hearing loss groups (n=10 per group). cVEMPs were recorded for 500 Hz, 1000 Hz, and 2000 Hz tone bursts. Amplitude and frequency amplitude ratios were analyzed using ANOVA with post hoc tests.

Results: Older adults with hearing loss showed significantly reduced amplitudes compared to young adults across all frequencies. Amplitude progressively decreased with increasing hearing loss severity, though it was not statistically significant between the hearing loss subgroups. Frequency amplitude ratios of persons with moderate and moderately severe hearing loss were significantly different from those of normal hearing. Frequency tuning shift towards 1000Hz was observed in mild hearing loss group. Responses were absent in a significantly higher proportion of persons with higher degree of hearing loss.

Conclusion: This study highlights saccular function in older adults across various degrees of hearing loss. It reveals tuning shift in cases of mild hearing loss, and a progressive decline in frequency-specific responsiveness with increasing hearing impairment.

Keywords: Cervical vestibular evoked myogenic potentials; older adults; hearing loss; amplitude; frequency tuning

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Introduction

With advancing age, both auditory and vestibular systems undergo structural and functional changes. Hearing loss in aging populations frequently co-occurs with vestibular dysfunction, creating complex challenges related to balance, posture, and mobility [1]. The changes in the vestibular system can affect cervical Vestibular Evoked Myogenic Potentials (cVEMP). Degenerative changes such as hair cell loss, diminished neural conduction, and compromised vascular supply to vestibular organs can markedly affect the amplitude and frequency tuning of cVEMP [2].

Various studies have consistently reported a decline in cVEMP amplitude and an increase in response thresholds among older adults with hearing loss, indicating a deterioration in saccular function with age and auditory decline [3, 4]. Older adults with Sensorineural Hearing Loss (SNHL) often exhibit reduced or absent cVEMP responses, especially at lower frequencies, which are typically optimal for saccular activation. Studies have reported that vestibular dysfunction, including impaired cVEMP responses, is more prevalent among individuals with bilateral SNHL, further suggesting a link between cochlear and vestibular decline [5, 6]. This relationship is believed to stem from shared vascular supply and proximity of the cochlear and vestibular end organs within the inner ear. Histopathological investigations [7] also support this connection, revealing concurrent degeneration of both cochlear and vestibular hair cells in aged temporal bones.

In addition to amplitude, frequency tuning of VEMP offers critical insights into otolith organ function [8]. Frequency tuning reveals the vestibular system's specific sensitivity to different sound frequencies, indicating its sensitivity, responsiveness, and integrity [9]. It has been reported that in older adults, frequency tuning of VEMP can detect subtle vestibular changes often overlooked by standard VEMP amplitude measurements [10]. It helps in distinguishing normal aging effects from pathological conditions such as Meniere's disease, vestibular neuritis, potentially facilitating earlier diagnosis [11]. Moreover, it can shed light on how changes in one sensory system (e.g., hearing loss) influence another (e.g., vestibular function), highlighting the complex interactions between auditory and vestibular pathways [12].

In older adults, a notable shift in frequency tuning has been observed, where cVEMP responses at 1000 Hz are relatively larger compared to those at 500 Hz. This results in an elevated Frequency Amplitude Ratio (FAR), suggesting a reduced sensitivity to low-frequency input [13]. This tuning shift and amplitude reduction at 500 Hz may thus reflect both age-related and pathology-driven degeneration of the saccule as well as its afferents. The elevated FAR observed in healthy older adults is probably due to a compensatory frequency tuning change, resulting from diminished responsiveness at lower frequencies and possibly reflecting broader cochleo-vestibular compromise [14].

While the evidence in literature indicates a shift in frequency tuning, its relationship with severity of hearing loss is not understood. A few studies have attempted to explore the relationship between hearing loss and vestibular function [13, 15], but none of the studies have investigated the frequency tuning of cVEMP in different severity of hearing loss. Frequency tuning is a sensitive marker of saccular function, and alterations in frequency tuning may precede complete absence of response, making it a valuable diagnostic tool. Thus, investigating cVEMP and their frequency tuning in older adults with different severity of hearing loss is crucial for understanding the complex interplay between the functioning of auditory and vestibular systems during aging. Clinically, frequency tuning of cVEMP is relevant, as its alterations can aid in differentiating pathologies such as Ménière's disease and age-related vestibular decline (presbystasis). By examining the impact of varying degrees of hearing loss on cVEMP, we can gain valuable insights into sensory decline in sacculo-collic pathway. Therefore, the aim of the present study was to explore amplitude and frequency tuning of cVEMP across different degrees of hearing loss in older adults.

Methods

Participants

In this cross-sectional study, 60 participants were recruited using purposive sampling from local communities and Audiology Clinics of the University. Two groups of participants were recruited. Group I consisted of 30 young adults (18 to 35 years) with normal hearing (≤25 dB HL at octave frequencies from 250 Hz to 8000 Hz). Group II comprised 30 older adults with bilateral SNHL. The age of the participants ranged from 50 to 70 years. Group II was further divided into three subgroups, each containing 10 participants. Group II A included older adults with mild hearing loss, whose Pure Tone Average (PTA) of 500, 1000, and 2000 Hz ranged from 26 to 40 dB HL. Group II-B included older adults with moderate hearing loss, whose PTA was ranged from 41 to 55 dB HL, and Group II C consisted of older adults with moderately severe hearing loss, whose PTA ranged from 56 to 70 dB HL. In group I, individuals with a history of Conductive Hearing Loss (CHL), dizziness or balance problems, retrocochlear pathology, or cognitive/neurological issues were excluded. In group II, individuals were excluded if they had CHL, retrocochlear pathology, central vestibular disorders, cognitive or neurological impairments, uncontrolled systemic conditions, uncorrected visual problems, postural hypotension, or psychiatric disorders. Additionally, individuals with a history of dizziness or balance issues prior to the age of 50 were also excluded.

Equipment

A calibrated GSI Piano audiometer, manufactured by Grason-Stadler (GSI) with corporate headquarters in Eden Prairie, Minnesota, United States, with TDH-39 supra-aural headphones and a Radioear B-71 bone vibrator was used for obtaining pure tone thresholds. The Interacoustics impedance meter AT235 (Interacoustics, Denmark) was used for immittance evaluation. Iteracoustics ECLIPSE EP25 system, a product of Interacoustics A/S from Denmark was used with its Version 4.4 software module for recording electromyography-scaled cVEMP.

Procedure

A comprehensive case history was collected to document any previous issues or complaints related to hearing or related disorders and dizziness. All the participants underwent pure-tone audiometry to assess the severity of hearing loss and immittance evaluation to rule out any conductive pathology prior to recording of cVEMP. In pure-tone audiometry, air conduction and bone conduction thresholds were measured using the Modified Hughson-Westlake method [16]. Hearing thresholds at 500, 1000, and 2000 Hz were averaged to determine the PTA. In immittance evaluation, tympanometry was carried out using 226 Hz probe tone. Acoustic reflexes were recorded for stimuli presented ipsilaterally and contralaterally at octave frequencies from 500 to 4000 Hz.

Cervical vestibular myogenic potentials

Rectified cVEMP waveforms were recorded in an acoustically treated room, with the participant seated comfortably in a chair to ensure proper posture during testing. The electrode sites were cleaned with a skin preparing gel to minimize impedance and a conducting paste was used while placing electrode to ensure good electrode contact. The electrode impedance was maintained below 5 kΩ to ensure optimal signal quality. The active (non-inverting) electrode was placed on the middle of the Sternocleidomastoid Muscle (SCM), while the inverting (reference) electrode was positioned on the upper part of the sternum. The ground electrode was placed on the participant's forehead. To activate the SCM, the participant was instructed to rotate their head towards the side opposite the ear being tested and to look towards that side. The participant was also asked to tighten their SCM by tucking their chin towards the opposite shoulder during each acoustic stimulation run. They were reminded to relax between trials to avoid muscle fatigue. Throughout the test, the rectified Electromyography (EMG) level was continuously monitored to maintain the level between 50 and 150 µV to ensure that the muscle activation was sufficient to ensure reliable responses.

cVEMP was recorded for 500, 1000, and 2000 Hz tone bursts. Stimuli were presented monaurally through insert earphones at 95 dB nHL, with a repetition rate of 5.1/s. The responses were passed through a band pass filter of 30 to 1500 Hz and amplified by a factor of 5000 and the responses for 200 stimuli were averaged. The time window for waveform analysis was set between 20 ms pre-stimulus and 80 ms post-stimulus to capture the p13 and n23 peaks. Two trials were recorded at each frequency to ensure good waveform reproducibility. A rest period was provided between recordings to prevent participant fatigue. The cVEMP waveforms were analyzed to record latency of p13 and n23 peaks, p13-n23 peak-to-peak amplitude.

Analysis

The data obtained from the participants were tabulated and subjected to the statistical analyses. Statistical analyses were carried out using JASP Statistics version 0.19.2. The Shapiro-Wilk test revealed a normal distribution. Hence, parametric tests were used to investigate the aims of the study. One-way ANOVA with post hoc analysis was carried out to investigate if the VEMP parameters differed significantly among different groups. A value of $p<0.05$ was considered as statistically significant.

Results

The mean age for group I was 27.6+4.4, for group II-A was 57.0±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 six females and four males, group II-A had five females and five males, group II-B comprised four females and six males, and group II-C included three females and seven males. cVEMP responses could be recorded from all 30 young adults whereas it was absent in some of the older adults with hearing loss. It can be observed from Figures 1 and 2 that none of the participants in the young adult group (group I) showed abnormal responses at any of the tested frequencies (500, 1000, and 2000 Hz). In contrast, older adults with hearing loss showed a progressive increase in abnormal responses for all the frequencies as the severity of hearing loss increased. In group II-A (mild hearing loss), most participants had detectable cVEMP responses, though the amplitudes were reduced. In the right ear, reduced amplitudes were observed in

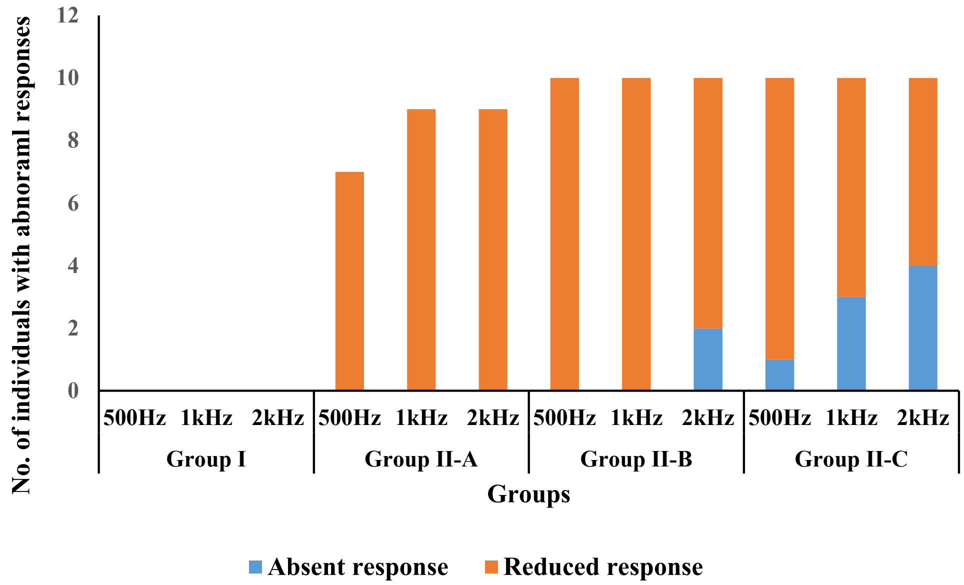

Figure 1. Number of persons with abnormal cervical vestibular evoked myogenic potentials in the right ear

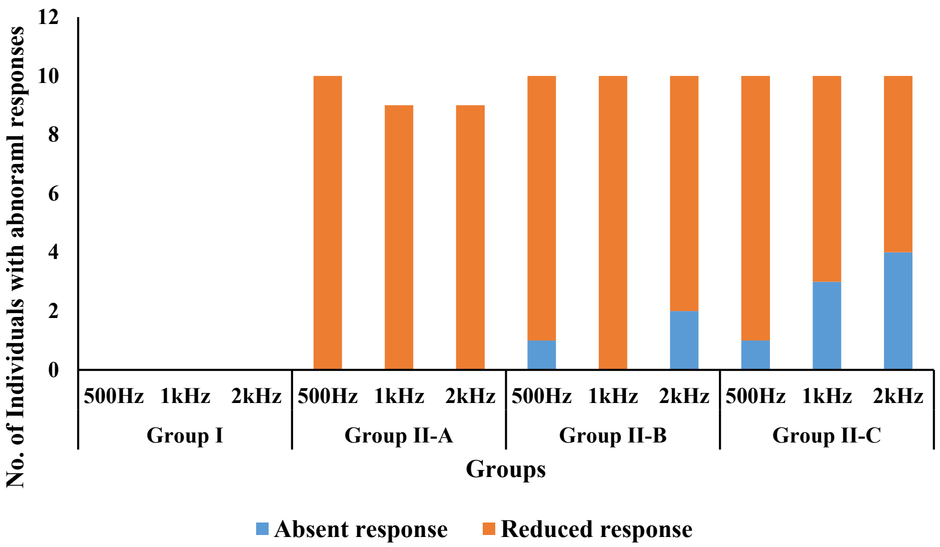

Figure 2. Number of persons with abnormal cervical vestibular evoked myogenic potentials in the left ear

eight participants for 500 while it was reduced for nine participants at 1000, and 2000 Hz. In the left ear, all the participants had reduced amplitude at 500 while nine participants had reduced amplitude at 1000, and 2000 Hz.

In group II-B (moderate hearing loss), all the participants exhibited abnormal cVEMP responses with reduced amplitudes at all frequencies. Additionally, two participants had absent responses in both ears at 2000 Hz, and one participant had an absent response at 500 Hz in left ear. Although all the participants exhibited abnormal responses, the highest percentage of absent responses was observed in group II-C (moderately severe hearing loss), particularly at 1000 Hz and 2000 Hz. Responses were absent in the right ear for two participants at 500 Hz, three participants at 1000 Hz, and four participants at 2000 Hz while in the left ear responses were absent for one participant at 500 Hz, two participants at 1000 Hz and three participants at 2000 Hz, as shown in Figures 3 and 4. A Chi-Square test was performed between the subgroups to examine if there is any association between severity of hearing loss and absence of cVEMP responses. A significant association was observed between group II-A and group

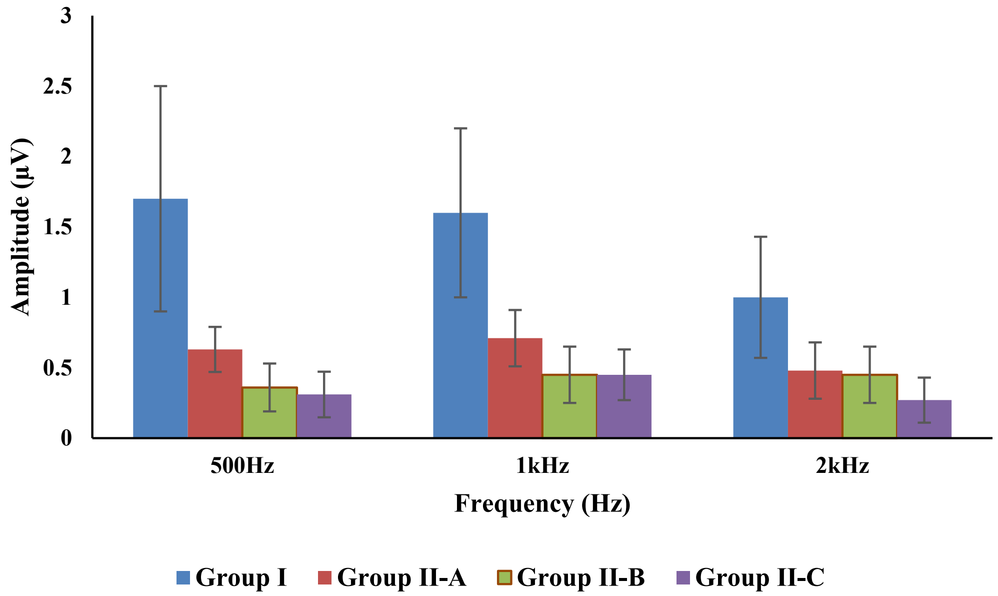

Figure 3. Amplitude (µV) across frequencies for right ear

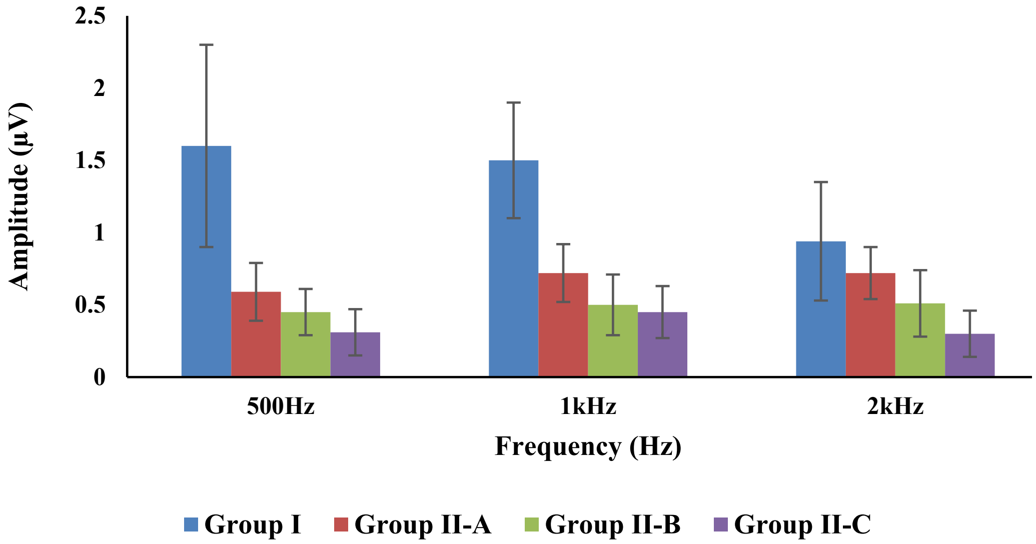

Figure 4. Amplitude (µV) across frequencies for left ear

Table 1. Frequency amplitude ratio for cervical vestibular evoked myogenic potentials

	Mean(SD) of FAR 1		Mean(SD) of FAR 2		Mean(SD) of FAR 3	
	Right ear	Left ear	Right ear	Left ear	Right ear	Left ear
Group I (normal hearing)	0.99(0.45)	0.98(0.37)	0.72(0.74)	0.76(0.61)	0.54(0.33)	0.57(0.43)
Group II-A (mild HL)	1.37(0.68)	1.51(0.43)	1.25(0.41)	1.17(0.64)	0.63(0.41)	0.65(0.46)
Group II-B (moderate HL)	1.22(1.26)	1.19(0.62)	1.10(0.53)	1.24(0.47)	0.86(0.46)	0.92(0.54)
Group II-C (moderately severe HL)	1.25(0.71)	1.21(0.58)	0.87(0.28)	0.72(0.33)	0.50(0.44)	0.48(0.29)

FAR; frequency amplitude ratio, HL; hearing loss

II-C at 1000 Hz and 2000 Hz, as well as between group II-B and group II-C at 1000 Hz. These findings suggest that as the severity of hearing loss increases, saccular responsiveness is progressively more compromised.

Since the data followed a normal distribution and involved more than one group, a one-way ANOVA was performed. The analysis was conducted to compare cVEMP amplitudes across different groups separately for 500, 1000, and 2000 Hz frequencies in both the right and left ears. The results revealed a main effect of group for all tested frequencies in the right ear (500 Hz: $F_{(3,55)}$=22.5, p<0.01; 1000 Hz: $F_{(3,55)}$=18.17, p<0.01; 2000 Hz: $F_{(3,50)}$=12.45, p<0.01) and in the left ear (500 Hz: $F_{(3,55)}$=26.06, p<0.01; 1000 Hz: $F_{(3,55)}$=16.68, p<0.01; 2000 Hz: $F_{(3,50)}$=5.05, p=0.005). The results of Tukey's Honest significant difference post hoc test indicated that the amplitude of those with normal hearing was significantly different from those with all groups of hearing loss for all the frequencies. The differences among subgroups with hearing loss were not statistically significant even though, a progressive reduction in amplitude was observed with increase in severity of hearing loss for all the frequencies.

Table 1 shows the descriptive statistics of Frequency Amplitude Ratios (FARs), FAR 1 (1000 Hz/500 Hz), FAR 2 (2000 Hz/500 Hz), and FAR 3 (2000 Hz/1000 Hz) calculated to evaluate frequency tuning for all the groups. In group I, responses at 1000 Hz were comparable to those at 500 Hz, while responsiveness declined at 2000 Hz. In group II-A, the amplitude of 1000 Hz response was relatively more than that at 500 Hz, with a gradual decline at 2000Hz. For group II-B, the amplitude of responses was similar at 500 Hz and 1000 Hz but showed a decline at 2000 Hz. In group II-C, there was a noticeable reduction in responses across all frequencies, with the most significant decline at 2000 Hz. Additionally, the findings revealed a shift in frequency tuning shift of cVEMP responses in older adults with mild hearing loss (group II-A). Amplitude at 1000 Hz was stronger than at 500 Hz, followed by a gradual decline at 2000 Hz. This suggests an altered vestibular sensitivity. In moderate hearing loss (group II-B), responses between 500 Hz and 1000 Hz remained relatively balanced, but a decline at 2000 Hz persisted, indicating further tuning alterations. In moderately severe hearing loss (Group II-C), a significant reduction in responses was observed across all frequencies, with the most pronounced decline at 2000 Hz, suggesting a substantial tuning shift and impaired frequency sensitivity.

It can be observed that ANOVA revealed a main effect of Group for all the FARs in both ears (FAR 1 [1000/500 Hz]: right ear, $F_{(3,55)}$=2.35, p=0.03; left ear, $F_{(3,55)}$=3.6, p=0.02; FAR 2 [2000/500 Hz]: right ear, $F_{(3,50)}$=3.89, p=0.04; left ear, $F_{(3,49)}$=4.57, p=0.01; FAR 3 [2000/1000 Hz]: right ear, $F_{(3,53)}$=2.34, p=0.03; left ear, $F_{(3,52)}$=2.73, p=0.049). Post hoc analysis demonstrated significant differences in FAR 1 between group I and group II-B, as well as between group I and group II-C, for both ears. Statistically significant differences were observed between group I and group II-C for FAR 2 and FAR 3.

Discussion

The present study investigated the amplitude of cVEMP and their frequency tuning characteristics in persons with varying degrees of hearing loss. For comparison, cVEMP was also recorded from young adults with normal hearing. In the present study, individuals with normal hearing exhibited clear and reproducible cVEMP waveforms across all tested frequencies, with strongest responses at 500 Hz. The responses at 1000 Hz were reduced compared to those at 500 Hz while a noticeable decline was observed at 2000 Hz. The frequency dependent nature of cVEMP responses is reinforced by these results, and align with similar trends reported in the literature [17]. Prior researchers have also reported that consistent cVEMP responses with maximum amplitude is obtained for 500 Hz tone burst stimuli in young adults with normal hearing and the response amplitudes tend to decrease when the frequency is increased to 1000 Hz [18].

Amplitude of cervical vestibular evoked myogenic potentials in older adults with hearing loss

The amplitude of cVEMP was significantly lesser than those with normal hearing at all the frequencies. There was a statistically significant difference between amplitude of normal hearing individuals to those with mild, moderate, and moderately severe hearing loss at 500, 1000 and 2000 Hz. This reduction in amplitude could be attributed to two possible factors: age and hearing loss. Also, a statistically significant association was observed between the absence or presence of cVEMP responses and increasing hearing loss severity in older adults. Specifically, a significant difference in cVEMP presence was noted between older adults with mild hearing loss and those with moderately severe hearing loss at both 1000 Hz and 2000 Hz. A similar pattern was observed at 1000 Hz when comparing moderate to moderately severe hearing loss. This indicates that as the degree of hearing loss increased, the number of absent cVEMP responses also increased. These results suggest a progressive decline in saccular responsiveness as hearing loss severity advances. These results align with previous research suggesting a close relationship between auditory and vestibular dysfunction in aging populations [19]. Similarly, it has been reported that hearing loss in older adults was strongly associated with reduced vestibular function, with those experiencing greater degrees of hearing impairment exhibiting poorer balance and increased fall risk [20]. Furthermore, reduced VEMP amplitudes in older adults with hearing loss suggest that age-related auditory decline contributes to decreased vestibular excitability [19]. Also, it has been reported that individuals with significant sensorineural hearing loss exhibit reduced or absent VEMP responses, indicating compromised saccular function [21]. This suggests that vestibular dysfunction is not merely a secondary effect of auditory impairment but rather a concurrent degenerative process. There is a dearth of studies investigating the effect of severity of hearing loss on vestibular dysfunction. In the current study, individuals with mild hearing loss exhibited a shift in frequency tuning, with stronger cVEMP responses at 1000 Hz compared to 500 Hz, followed by a gradual decline at 2000 Hz. In individuals with moderate hearing loss, cVEMP responses showed greater abnormalities, there was a reduction in the response rate and when responses were present, the amplitude was reduced for all the frequencies. As the severity of hearing loss progressed to moderately severe, a higher number of absent responses were observed, and the cVEMP amplitudes at all frequencies were further reduced compared to those with mild and moderate hearing loss. Thus, the results of the present study indicate that as the severity of hearing loss increases, saccular function declines significantly, which can lead to impairments in balance and spatial awareness. This aligns with previous findings that sensorineural hearing loss influences overall vestibular functioning including saccular function thereby affecting the generation of cVEMP responses. These findings suggest that vestibular dysfunction becomes more pronounced as auditory impairment worsens [22].

Frequency tuning of cervical vestibular evoked myogenic potentials in older adults with hearing loss

A tuning shift in cVEMP responses towards 1000 Hz was observed in all older adults with mild to moderately severe hearing loss. FAR 1 (1000 Hz/500 Hz) was higher in older adults with SNHL when compared to that of young adults with normal hearing. Statistically significant difference was observed between normal hearing individuals and those with moderate and moderately severe hearing loss for FAR 1. This aligns with existing literature, which reports that in normal-hearing young individuals, a 500 Hz tone burst typically elicits the largest amplitude response due to the saccule's natural tuning properties [17]. In older adults with SNHL, cVEMP response amplitudes to low-frequency stimuli such as 500 Hz are often more reduced compared to responses at higher frequencies like 1000 Hz. This leads to an elevated FAR, which may be attributed to shared cochleo-vestibular degeneration or vascular compromise affecting low-frequency-tuned hair cells [22].

Statistically significant differences were also observed between young adults and older adults with moderately severe hearing loss for FAR 2 (2000/500) and FAR 3 (2000/1000). The present findings suggest that with increasing severity of hearing loss in older adults, the amplitude differences across VEMP frequencies

(500, 1000, and 2000 Hz) gradually decrease. In cases of moderately severe hearing loss, this frequency tuning appears to flatten, and the reduction in amplitude from 500 Hz to 1000 Hz becomes less pronounced, or even absent. An elevated FAR2 suggests significant compromise in the saccule's preferred low-frequency sensitivity. While FAR2 offers a broad perspective, FAR3 provides more granular insight into the mid-to-higher frequency range of saccular tuning giving information about how well the saccule responds across a broader spectrum of frequencies. This reduction in frequency-selective amplitude likely reflects an alteration in the tuning of the vestibular end organs, specifically the saccular macula, and its associated neural pathways. The tuning of cVEMP responses is influenced by multiple factors, including the saccule, its hair cells, ionic currents, and the afferent fibers [23].

The findings of the present study align with the prior research demonstrating a smaller difference in the amplitude of cVEMP at 500, 1000 Hz and 2000 Hz in older adults suggest a general reduction in vestibular sensitivity and frequency discrimination [24]. It has been emphasized that hearing loss can modify vestibular function by affecting the pathways between the cochlear and vestibular systems, leading to changes in the way otolith organs respond to sound stimuli [25]. Some researchers have postulated that this shift in tuning suggests altered vestibular sensitivity due to early auditory impairment [26].

Although several studies have examined saccular function in older adults with hearing loss, comprehensive evaluations across different severity of hearing loss have not been conducted. Therefore, this study investigated saccular function in older adults with varying degrees of hearing loss. The findings of this study highlight the need for comprehensive vestibular assessments in individuals with SNHL, particularly those with moderate to moderately severe hearing loss. The observed decrease in the amplitude of cVEMP in older individuals is probably a consequence of the well-documented histopathological changes that naturally occur in the vestibular system with aging [27].

Frequency tuning of cVEMP responses is clinically significant, especially in older adults. A shift towards higher optimal frequencies can occur due to age-related vestibular changes, which should be differentiated from Meniere's disease. Therefore, comprehensive testing including recording of cVEMP at different frequencies is crucial to avoid misdiagnosis and guide appropriate management.

The limitations of the present study include a small sample size within each subgroup (n=10), which may limit the generalizability of the findings and reduce the ability to detect subtle differences. Additionally, the study did not adequately control for confounding variables such as age. Age-matching among older adult subgroups could have more effectively distinguished the effects of age from those of hearing loss severity. Furthermore, the study did not include a comparison group of age-matched older adults with normal hearing.

Conclusion

The present study showed that saccular function, as assessed by amplitude and frequency tuning characteristics of cervical Vestibular Evoked Myogenic Potentials (cVEMP) responses progressively deteriorates with increasing severity of sensorineural hearing loss in older adults. A notable shift in frequency tuning towards 1000 Hz and a reduction in cVEMP amplitude, particularly at 500 Hz were observed in individuals with mild to moderately severe hearing loss, indicating early vestibular involvement. The flattening of the frequency tuning curve and elevated frequency amplitude ratios suggests a decline in the frequency-specific responsiveness of the saccule, probably due to shared cochleo-vestibular degeneration. These findings underscore the importance of assessing vestibular function alongside auditory evaluation in aging populations and highlight the need for longitudinal studies to further explore the trajectory of vestibular decline in relation to hearing loss.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Institutional ethical committee of Bharati Vidyapeeth (Deemed to be University) Medical College in 2021 with Ref No. BVDUMC/IEC/58. Following the rules of the ethical committee, the informed consent was obtained from each participant.

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Authors' contributions

NN: Study design, data acquisition, statistical analysis, manuscript preparation; CSV: Study design and supervision, manuscript editing, manuscript review.

Conflict of interest

There is no conflict of interest.

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