CERVICAL, OCULAR, AND MASSETER VEMPS IN INDIVIDUALS WITH MODERATE TO PROFOUND SENSORINEURAL HEARING LOSS

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A Dissertation Submitted in Part of Fulfilment of

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CERTIFICATE

This is to certify that this dissertation entitled **"Cervical, Ocular and Masseter VEMPs in Individuals with Bilateral Moderate to Profound Sensorineural Hearing Loss"** is a bonafide work submitted as part of fulfilment of the degree of Master of Science (Audiology) of the student with Registration Number **P01II24S023010.** This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled **"Cervical, Ocular and Masseter VEMPs in Individuals with Bilateral Moderate to Profound Sensorineural Hearing Loss"** has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled ""**Cervical, Ocular and Masseter VEMPs in Individuals with Bilateral Moderate to Profound Sensorineural Hearing Loss**" is the result of my own study under the guidance of Ms. Nirupama S., Assistant Professor of Audiology, and under the Co-guidance of Dr. Sujeet Kumar Sinha, Associate Professor of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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"Mysore tested me in ways I was not prepared for but it also gave me more than I ever came looking for"

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This dissertation may carry my name on the cover, but in many ways, it belongs to all of you.

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LIST OF ABBREVIATION

VEMP- Vestibular Evoked Myogenic Potential

cVEMP- Cervical Vestibular evoked myogenic potential

oVEMP- Ocular Vestibular evoked myogenic potential

mVEMP- Masseter Vestibular evoked myogenic potential

SSNHL- Sudden sensorineural hearing loss.

vHIT- Video Head Impulse Test.

ABSTRACT

The cochlea and vestibular end organs share a common embryological origin and anatomical proximity, making vestibular dysfunction a frequent comorbidity in individuals with sensorineural hearing loss (SNHL). Cervical VEMP (cVEMP), ocular VEMP (oVEMP), and masseter VEMP (mVEMP) assess the sacculo-collic, utriculo-ocular, and vestibulo-trigeminal reflex pathways, respectively. While cVEMP and oVEMP findings in SNHL have been studied, mVEMP remains largely unexplored in this population. The present study aimed to compare all three VEMPs in adults with bilateral moderate-to-profound SNHL and to examine correlations among them.

Twenty adults with bilateral moderate-to-profound SNHL and 20 age- and gender-matched normal-hearing adults participated in the study. cVEMP, oVEMP, and mVEMP were recorded using 500 Hz tone burst stimuli at 125 dB peSPL. Response rate, latency, rectified amplitude, and asymmetry ratio were compared between groups.

Response rates in the SNHL group were reduced across all three VEMPs (cVEMP: 90%, oVEMP: 75%, mVEMP: 55%), with the reduction being statistically significant only for mVEMP ($p = 0.008$). Latency did not differ significantly between groups for any VEMPs ($p > 0.05$). Rectified amplitude was significantly lower in the SNHL group for cVEMP ($p = 0.017$) and mVEMP ($p = 0.006$), while oVEMP amplitude showed no significant difference. The oVEMP asymmetry ratio was significantly higher in the SNHL group ($p = 0.045$). Correlation analysis revealed mostly non-significant associations among the three VEMPs in both groups.

The findings indicate that the vestibulo-trigeminal pathway is the most affected in bilateral moderate-to-profound SNHL, with mVEMP showing the greatest reduction in response rate and amplitude. Preserved latencies suggest that neural conduction timing remains intact despite

reduced response strength. The lack of significant inter-VEMP correlations supports that each VEMP evaluates an independent vestibular reflex pathway. Including mVEMP alongside cVEMP and oVEMP may improve the detection of hidden vestibular dysfunction in individuals with SNHL.

Keywords: *Masseter Vestibular Evoked Myogenic Potentials, Cervical Vestibular Evoked Myogenic Potentials, Ocular Vestibular Evoked Myogenic Potentials, Sensorineural Hearing Loss, Vestibulo-trigeminal pathway.*

Chapter 1

Introduction

Vestibular evoked myogenic potentials (VEMPs) are an important component of vestibular assessment battery that evaluates the otolith function (Mattingly et al., 2019). VEMPs are basically inhibitory or excitatory electromyographic potentials generated in response to intense acoustic, vibratory or electric stimuli (Katz et al., 2015). Cervical VEMP (cVEMP) refers to the inhibitory sacculo-collic response that is obtained from the sternocleidomastoid muscle. It offers valuable insights into the role of the saccule and the inferior vestibular nerve (Musiek et al., 2011). The ocular vestibular evoked myogenic potential (oVEMP) is recorded from extraocular muscles and serves as an indicator of the functional integrity of the utriculo-ocular reflex pathway, which is primarily mediated by the superior vestibular nerve (Mattingly et al., 2019; Papathanasiou, 2012). Collectively, cVEMP and oVEMP are useful in assessing the saccular and utricular function (Bansal et al., 2013; Mattingly et al., 2019).

One of the latest developments in VEMPs is the masseter VEMP. Masseter VEMP refers to the electromyographic potentials generated from the masseter muscle in response to an intense acoustic stimulus. It is believed to originate from the vestibular organ, most likely the saccule and travel through the trigeminal motor nuclei, thereby assessing the vestibulo-trigeminal reflex pathway (Nagarajan & Sinha, 2024). Unlike cVEMP and oVEMP, mVEMP differs not only in the muscle from which it is recorded but also in the neural pathway that it involves. As it involves the Trigeminal motor pathway, it makes mVEMP more sensitive to the brainstem pathology than cVEMP or oVEMP (Nagarajan & Sinha, 2024; Thirusangu & Thomas, 2025). With increasing research interest and clinical utility, mVEMP is now being recognised as a useful tool in standard

vestibular assessment that may improve our clinical understanding of vestibular and brainstem interactions (Nagarajan & Sinha, 2024).

In clinical practice, cVEMP and oVEMP are commonly used as a part of the test battery of vestibular evaluation, especially in cases where otolith dysfunction is suspected (Papathanasiou, 2016; Welgampola & Colebatch, 2005). They are frequently used to detect abnormalities in conditions such as Ménière's disease (Scarpa et al., 2019), vestibular neuritis (Scarpa et al., 2019), superior semicircular canal dehiscence (SCD) (Hunter et al., 2017; Zuniga et al., 2013), and central vestibulopathies (Welgampola & Colebatch, 2005). For example, SCD shows abnormally low thresholds and high amplitudes in cVEMP, which have become part of the diagnostic profile for the disorder (Govender et al., 2016; Welgampola & Colebatch, 2005). In addition to identifying peripheral vestibular lesions, VEMP testing can also help assess central vestibular pathways (Papathanasiou, 2016; Welgampola & Colebatch, 2005).

VEMP testing has also become increasingly important in cochlear implantation cases. Since the cochlea and vestibular system are located within the same bony labyrinth and share the same blood supply, there might be a risk of vestibular damage in cochlear implantation (Katsiari et al., 2013; Licameli et al., 2009). Preoperative VEMP assessment helps in baseline vestibular evaluation, while post-operative assessment helps in comparing the results with pre-operative results after cochlear implantation, to identify any changes that might have occurred because of surgery (Colin et al., 2018; Licameli et al., 2009). These applications show that VEMP testing is useful not only for diagnosis, but also for clinical decision-making and patient counselling in otology and audiology (Licameli et al., 2009).

This strong connection between the cochlea and vestibular system has also been observed in individuals with sensorineural hearing loss (SNHL). As we know, the cochlea, saccule, and

utricle have a common embryological origin, share the same blood supply, and are anatomically situated very close to each other, making them susceptible to similar pathologies (Golz et al., 2001; Perez et al., 2000). Therefore, people with SNHL may also experience vestibular dysfunction, even when they do not have any balance-related symptoms. Research has also supported that otolith organ dysfunction is frequently present in individuals with profound SNHL. Hong et al. (2008) identified abnormal cVEMP responses in approximately 26.9% of adults diagnosed with profound SNHL, indicating compromised saccular function among individuals with sensorineural hearing loss. These findings were further corroborated by Xu et al., (2016) and Zhang et al., (2024) , who documented a substantial proportion of absent or abnormal VEMP responses in both pediatric and adult SNHL populations, implying that vestibular dysfunction may frequently go undetected in such individuals.

Studies on individuals with SNHL have further shown the presence of otolith dysfunction in SNHL group. Al-Ghandour et al., (2024) reported that individuals with bilateral long-term sensorineural hearing loss had absent or reduced cVEMP and oVEMP, indicating that damage may affect both the cochlea and the otolith system. However, some individuals with SNHL had normal VEMPs, indicating vestibular involvement and progression of pathology among people. These varied findings suggest that the severity and aetiology of SNHL may differentially influence the extent of vestibular involvement.

Recent research on mVEMP suggests it may provide additional diagnostic information beyond traditional VEMPs. More importantly, mVEMP is found to be more sensitive to brainstem pathology or to pathologies involving the trigeminal nerve or its nuclei. For example, De Natale et al., (2015) reported that abnormalities in mVEMP were observed more frequently than those in cVEMP and oVEMP among individuals diagnosed with Parkinson's disease, indicating early

compromise of the vestibulo-trigeminal pathway. Consistent findings were reported by Magnano et al. (2014, 2016) in individuals with multiple sclerosis (MS), wherein deviant mVEMP responses were detected even in cases where conventional VEMP assessments yielded normal results. These results indicate that mVEMP may be useful in detecting central demyelination involving the trigeminal pathway. Sangu Srinivasan et al.(2022) identified mVEMP abnormalities in 82% of individuals with MS, and mVEMPs were more effective than both cVEMPs and oVEMPs in detecting brainstem dysfunction. Overall, these findings suggest that mVEMP may be more useful than the other VEMPs in identifying conditions affecting the central nervous system or the trigeminal pathway.

In addition to neurological disorders, mVEMP has been shown to be useful for identifying abnormalities associated with auditory and vestibular conditions. Kalaiyarasan and Sinha (2024) found affected mVEMP responses in individuals with auditory neuropathy spectrum disorder (ANSD), suggesting possible involvement of vestibulo-trigeminal pathways. de Natale et al. (2018) found impaired mVEMP responses in individuals with REM sleep behaviour disorder, a condition associated with early alpha-synuclein pathology, further supporting the sensitivity of mVEMP towards early brainstem dysfunction. Comacchio et al. (2025) found that mVEMP responses were often present even when cVEMP responses were absent on the affected side in vestibular neuritis. This suggests that the vestibulo-trigeminal pathway may still function normally despite damage to the inferior vestibular nerve. These findings show that mVEMP may help identify which branch of the vestibular nerve is affected.

Need for the Study

Although the relationship between SNHL and vestibular dysfunction is well recognized, the specific involvement of otolith pathways in individuals with bilateral moderate-to-profound

SNHL has not been thoroughly investigated. Most studies conducted in this population have primarily focused on cVEMP and oVEMP findings, while the contribution of mVEMP in evaluating vestibular involvement remains insufficiently explored.

There is a lack of information on the comparison between cVEMP, oVEMP, and mVEMP in individuals with bilateral SNHL. Comparing these responses may help in understanding whether certain reflex pathways are more affected by hearing loss and whether mVEMP can provide additional information not available from conventional VEMP tests.

Understanding these relationships is important from a clinical perspective. If mVEMP can detect abnormalities not identified by cVEMP or oVEMP, adding it to routine assessment may improve the detection of otolith dysfunction in people with hearing impairment. On the other hand, if some VEMP pathways remain normal, it may indicate that certain vestibular structures are less affected or relatively preserved. Early identification of vestibular involvement is important in individuals with SNHL, as vestibular dysfunction can affect balance, spatial orientation, and overall quality of life. Therefore, assessing all three VEMP modalities together may help plan more targeted vestibular rehabilitation and improve patient outcomes.

Since no comparative studies have evaluated cVEMP, oVEMP, and mVEMP in individuals with bilateral moderate-to-profound SNHL, there is a need to assess the relative sensitivity and diagnostic value of these pathways. The findings of the study may enhance our understanding of otolith involvement in hearing loss and support a more comprehensive vestibular assessment in this population.

Aim of the Study

The aim of the present study was to compare the cervical, ocular, and masseter vestibular evoked myogenic potentials (cVEMP, oVEMP, and mVEMP) in adults with bilateral moderate to

profound sensorineural hearing loss. The study also aimed to establish a correlation among cVEMP, oVEMP, and mVEMP in individuals with moderate to profound sensorineural hearing loss.

Objectives of the study:

1. To compare the response rate of cVEMP, oVEMP, and mVEMP in adults with bilateral moderate to profound SNHL.
2. To compare the latency and amplitude parameters of cVEMP, oVEMP, and mVEMP between the SNHL group and the healthy group.
3. To determine the correlation between cVEMP, oVEMP, and mVEMP latency and amplitude parameters in healthy and SNHL groups.

Chapter-2

Review of literature

Vestibular problems have been commonly reported in people with sensorineural hearing loss (SNHL), suggesting that the hearing and balance structures of the inner ear are often affected together. Histopathological studies have revealed structural deterioration of the saccule and utricle in cases of severe cochlear damage (Perez et al., 2000; Golz et al., 2001), suggesting that cochlear pathology does not remain limited to the auditory system but may propagate to neighbouring vestibular structures. Clinical studies have shown that abnormal vestibular responses are more common in individuals with moderate to profound SNHL than in those with normal hearing. Despite differences across studies, the overall evidence suggests that vestibular dysfunction is commonly present in individuals with SNHL, even if they do not show symptoms

2.1 Cervical VEMP Findings in Sensorineural Hearing Loss

In a study by Akin et al. (2012), Air-conducted tone burst stimuli were used to evaluate cVEMP responses in 43 individuals with noise-induced SNHL alongside 14 age-matched controls. While all controls gave normal results, abnormal responses were identified in 33% of the SNHL group, with thresholds increasing in line with hearing loss severity. The authors determined that noise exposure compromises both saccular and cochlear structures, and that cVEMP abnormalities point to involvement of the sacculo-collic pathway.

Selim et al. (2012) administered air-conducted cVEMP using click stimuli at 100 dB nHL in 30 children with congenital or acquired SNHL and 25 normally hearing controls. While P1 and N1 latencies did not differ significantly between the two groups, amplitudes were significantly reduced, and thresholds were elevated in the hearing-impaired group. The study pointed to a high

prevalence of hidden saccular dysfunction in paediatric SNHL and highlighted the need for routine vestibular screening in this population.

Singh et al. (2012) recorded cVEMP using 500 Hz air-conducted tone burst stimuli in 15 children with severe-to-profound SNHL and 10 normally hearing controls. Mean P1 latency was 15.12 ms and N1 latency was 23.86 ms in the SNHL group, compared to 15.39 ms and 23.68 ms in controls, with no statistically significant difference between the groups. However, peak-to-peak amplitude was significantly reduced in the hearing-impaired group, leading the authors to conclude that amplitude is a more sensitive indicator of vestibular dysfunction than latency in children with SNHL.

In a study focused on older adults, Zuniga et al. (2012) recorded air-conducted cVEMP using 500 Hz tone burst stimuli at 125 dB SPL in 51 individuals aged 70 years and above. A significant negative correlation was observed between high-frequency hearing thresholds and cVEMP amplitude ($r = -0.37$, $p < 0.01$), suggesting that greater hearing loss was associated with poorer saccular function. The findings pointed towards a shared degenerative process affecting both cochlear and saccular structures in the ageing inner ear.

Niu et al. (2015) used 500Hz air-conducted tone burst stimuli to evaluate both cVEMP and oVEMP in 170 individuals with unilateral sudden SNHL across different age groups and age-matched controls. Response rates for cVEMP were 53.5% in affected ears, 71.2% in contralateral ears, and 84.8% in normal ears. The considerably lower response rate in affected ears indicated vestibular involvement, leading the authors to conclude that otolith dysfunction commonly accompanies sudden SNHL and that VEMP findings should be understood in this light. Additionally, VEMP response rates were found to decline with increasing age, highlighting the importance of considering age when interpreting VEMP findings.

Lotfi et al. (2014) evaluated saccular function using air-conducted cVEMP in 30 children with bilateral severe-to-profound SNHL who were candidates for cochlear implantation and 17 normally hearing controls. Thresholds were significantly elevated and amplitudes were reduced in the SNHL group. Bilateral absent responses were observed in 26.66% of the hearing-impaired group, with no such finding in controls. The study emphasised the presence of saccular dysfunction in this population and recommended vestibular evaluation prior to cochlear implantation.

Ledesma et al. (2014) Conducted a systematic review that included 15studies on the use of VEMP in sudden SNHL. The majority of studies used air-conducted stimuli, and around 67% reported that the presence of a VEMP response was linked to better hearing recovery. It was concluded that VEMP serves as a useful tool for both evaluation and prognosis prediction in sudden SNHL.

Xu et al. (2015) examined saccular function using air-conducted 500 Hz tone burst cVEMP in 43 children with profound SNHL and 20 healthy controls. The response rate was 61.9% in the SNHL group compared to 100% in controls. Thresholds were significantly elevated and amplitudes were reduced in the hearing-impaired group ($p < 0.05$). The authors concluded that vestibular involvement in children with profound SNHL is common but often goes clinically undetected.

In a follow-up study on adults, Xu et al. (2016) recorded air-conducted 500 Hz tone burst cVEMP in 29 adults with profound SNHL and 20 healthy controls. The response rate dropped to 44.4% in the SNHL group compared to 100% in controls. Thresholds were significantly elevated ($p < 0.001$), amplitudes were significantly reduced ($p = 0.024$), and latencies were found to be shortened in the SNHL group. The study reinforced the view that hidden otolith dysfunction is common even in adults with SNHL who present without obvious vestibular complaints.

Abdoli (2017) recorded cVEMP using a 500Hz air-conducted tone burst at 125dB peak SPL in 60 elderly males with age-related SNHL. Individuals with flat audiograms showed longer latencies and lower amplitudes compared to controls ($p < 0.05$), suggesting that cochlear and saccular structures undergo parallel mechanical deterioration.

Takeuti et al. (2019) recorded air-conducted cVEMP using 500 Hz tone burst stimuli in 31 adults with profound prelingual bilateral SNHL and 33 controls. Abnormal responses were present in 35.5% of the SNHL group compared to 6.1% in controls ($p < 0.05$). The aetiology and timing of hearing loss were found to significantly influence saccular dysfunction, with infectious and prenatal causes leading to higher abnormality rates.

Wang et al. (2019) administered air-conducted cVEMP using 500 Hz tone burst stimuli in 82 patients with sudden SNHL and 30 controls. In the control group, mean p13 and n23 latencies were 13.13 ± 2.89 ms and 23.51 ± 3.25 ms, respectively. These latencies were significantly longer in the SNHL group ($p = 0.017$), leading the authors to conclude that cVEMP is a valuable clinical tool for detecting vestibular involvement in sudden SNHL.

Ciodaro et al. (2020) used 500 Hz tone burst stimuli at 105 dB nHL to record air-conducted cVEMP in 20 adults with moderate-to-profound SNHL and 15 normal-hearing controls. The P1–N1 complex was identified in only 29 of 40 ears in the SNHL group, while all control ears showed its presence. The considerable rate of absent or abnormal responses suggested a high prevalence of saccular dysfunction, prompting the authors to advocate for routine vestibular screening in individuals with moderate-to-profound SNHL.

Beshr et al. (2020) recorded air-conducted cVEMP using 500 Hz tone burst stimuli at 95 dB nHL in 40 adults with unilateral SNHL. Absent or abnormal responses were found in 45% of affected ears. P1 and N1 amplitudes were significantly reduced compared to normal ears ($p = 0.013$

and p = 0.002, respectively). The study highlighted that saccular involvement may be present even in individuals with SNHL who do not have balance-related symptoms.

El Kousht et al. (2021) compared air-conducted and bone-conducted cVEMP in 10 SNHL patients and 10 normal-hearing controls. Response rates were 100% in both groups; however, amplitudes were significantly reduced in the SNHL group. A positive correlation was found between cVEMP and oVEMP latencies and the degree of hearing loss in the SNHL group. The study confirmed that saccular dysfunction can be identified regardless of the stimulus type used and that latency changes may be more evident with increasing hearing loss severity.

Apeksha & Devananda (2022) Conducted a systematic review including 21 studies evaluating cVEMP in children with SNHL. The included studies mainly used air-conducted tone bursts and clicks. Significant vestibular abnormalities were reported, particularly in cochlear implant recipients. Based on these findings, the authors recommended vestibular monitoring both before and after implantation.

Deepak Raj PV and Dr. Ravanan MP (2022) evaluated vestibular function in children diagnosed with SNHL using air-conducted stimuli. Their findings revealed that more than half of the participants (57%) showed abnormal or absent responses, and in ears with severe-to-profound hearing loss, complete absence of responses was recorded in 65% of cases, highlighting the high prevalence of vestibular dysfunction in the SNHL group.

Liang et al. (2022) evaluated air-conducted cVEMP and oVEMP responses in 64 patients with unilateral idiopathic sudden SNHL using 500 Hz tone burst stimuli. Half of the patients in the ineffective treatment group demonstrated abnormal cVEMP responses, whereas those with normal cVEMP showed greater hearing improvement. These results indicate that cVEMP may serve as a potential indicator of hearing recovery outcomes in sudden SNHL.

Zakaria et al. (2023) compared 500 Hz tone burst and narrowband CE-Chirp stimuli at 125 dB peSPL for cVEMP recording in 50 adults with bilateral SNHL. The use of CE-Chirp stimulus resulted in notably shorter P1 and N1 latencies ($p < 0.001$, $d > 0.80$), while amplitude values were comparable between the two stimuli. The findings suggested that CE-Chirp stimuli produce better neural synchrony and may be a more efficient option for cVEMP recording in individuals with SNHL.

Shen et al. (2024) assessed cVEMP in 96 children with severe SNHL who were being evaluated for cochlear implantation, including those with vestibular malformations and large vestibular aqueduct syndrome. Response rates varied across groups, with 37.5% in children with vestibular malformations, 64% in those with large vestibular aqueduct syndrome, and 58.51% in children with SNHL with no structural abnormalities. These findings indicated that children with SNHL are particularly vulnerable to otolith dysfunction and supported the routine inclusion of VEMP testing as part of pre-cochlear implant vestibular evaluation.

Across paediatric, adult, sudden, noise-induced, and age-related SNHL populations, the available evidence consistently points to a strong association between SNHL and saccular dysfunction. The most frequently reported abnormalities are reduced response rates, diminished amplitudes, and elevated thresholds. Latency changes appear less consistent across studies, though some evidence suggests they may emerge as hearing loss severity increases. Several studies also indicate that cVEMP abnormalities may carry prognostic value in sudden SNHL. Together, these findings support the clinical relevance of cVEMP as part of a comprehensive vestibular evaluation in individuals with SNHL.

2.2 Ocular Vestibular Evoked Myogenic Potentials (oVEMP) in Sensorineural Hearing Loss

The ocular vestibular evoked myogenic potential (oVEMP) is an objective electrophysiological test that assesses the function of the utricle and the superior vestibular nerve pathway. Compared to cVEMP, oVEMP has been explored less frequently in individuals with SNHL. Nevertheless, existing studies indicate that utricular dysfunction may occur across various forms and severities of hearing loss, including paediatric, adult, congenital, and sudden SNHL.

Zhang et al. (2013) recorded oVEMP using conventional air-conducted stimuli in 40 patients with unilateral sudden SNHL and 30 normal-hearing controls. The oVEMP response rate was significantly lower in affected ears (40.0%) compared to normal ears (71.7%), with contralateral ears intermediate (57.5%). No significant differences were found for any other oVEMP parameters including threshold, N1 latency, P1 latency, latency interval, or amplitude between the groups. The authors concluded that utricular dysfunction is frequently seen in sudden SNHL and that oVEMP provides objective monitoring of otolithic damage in this population.

Bansal et al. (2013) recorded oVEMP using 500 Hz air-conducted tone burst stimuli in 23 individuals with bilateral severe-to-profound congenital SNHL and 23 normal-hearing controls. While all control participants showed oVEMP responses, only 66% of those in the SNHL group did. The authors concluded that utricular dysfunction is present in congenital SNHL and may be more commonly affected than the saccule in this population.

P. Wang et al. (2015) recorded oVEMP using 500 Hz air-conducted tone burst stimuli at 95 dB nHL in 35 patients with unilateral sudden SNHL and 55 healthy controls. In the control group, mean P1 latency, N1 latency, and P1–N1 amplitude were 11.92 ± 0.85 ms, 17.07 ± 1.04 ms, and 5.44 ± 2.53 μV, respectively. Affected ears demonstrated significantly lower amplitudes compared to both contralateral and control ears, leading the authors to conclude that air-conducted oVEMP is an effective tool for identifying utricular dysfunction in sudden SNHL.

Xu et al. (2015) recorded oVEMP using air-conducted sound stimuli in 43 children with profound SNHL and 20 healthy children. The oVEMP response rate was 58.1% in the SNHL group and 100% in controls, with significantly elevated thresholds and reduced amplitudes ($p < 0.05$) in those who showed responses in the SNHL group. The authors concluded that hidden utricular dysfunction is common in children with profound SNHL.

Xu et al. (2016) examined oVEMP responses to air-conducted sound in 29 adults with profound SNHL and 20 healthy controls. The response rate in the SNHL group was markedly lower at 38.9% compared to 100% in controls. Where responses were present, thresholds were significantly elevated ($p < 0.001$) and amplitudes were significantly reduced ($p = 0.022$). The authors concluded that utricular dysfunction is common in adults with profound SNHL, even when not immediately apparent clinically.

Y. Wang et al. (2019) recorded oVEMP responses in 82 sudden SNHL patients (with and without vertigo) and 30 controls. Mean n10 latency and n10–p15 amplitude were 10.13 ± 0.48 ms and 5.58 ± 2.34 μV in healthy subjects. Abnormal rates were higher in patients with vertigo, leading the authors to conclude that oVEMP is valuable for assessing utricular damage and predicting prognosis in sudden SNHL.

Beshr et al. (2020) evaluated air-conducted cVEMP and oVEMP responses in 40 adults with unilateral sensorineural hearing loss using 500 Hz tone burst stimuli presented at 95 dB nHL. The study reported abnormal or absent oVEMP responses in 47.5% of affected ears. Significantly reduced oVEMP amplitudes were observed in the hearing-impaired ears, whereas latency differences between affected and unaffected ears were not statistically significant. The authors concluded that vestibular dysfunction may coexist with SNHL even in the absence of obvious vestibular symptoms.

Tanyeri et al. (2020) evaluated cVEMP and oVEMP responses in 26 adults with prelingual SNHL and 26 normal-hearing controls. Lower response rates were observed in the SNHL group, with oVEMP responses present in only 44.2%. Significant differences were observed for oVEMP amplitudes between the groups. The authors concluded that both utricular and saccular dysfunction may coexist in individuals with prelingual SNHL.

El Kousht et al. (2021) compared air- and bone-conducted cVEMP and oVEMP responses in individuals with SNHL, conductive hearing loss, and normal hearing. Using click stimuli, the study reported 100% response rates in the SNHL group. Although oVEMP amplitudes and latencies did not differ significantly from controls, a significant positive correlation was observed between VEMP latencies and the degree of hearing loss. The authors concluded that vestibular dysfunction may coexist with SNHL and may become more evident with increasing hearing loss severity.

Gadsbøll et al. (2022) examined vestibular function in 42 children with unilateral or bilateral SNHL using oVEMP, cVEMP, and vHIT. The study reported abnormal vestibular findings in 28.6% of the children, and ears with multiple abnormal vestibular findings had significantly greater hearing loss severity ($p = 0.008$). The authors suggested that vestibular dysfunction may commonly coexist with childhood SNHL, so vestibular evaluation should be performed even in young children.

Shen et al. (2023) assessed cVEMP and oVEMP responses in 96 children with severe-to-profound SNHL, including children with vestibular malformations and LVAS, using 500 Hz tone burst stimuli at 105 dB nHL. Children with vestibular malformations showed significantly lower oVEMP response rates (42.86%) compared to the LVAS and control groups ($p = 0.023$), along with significant differences in latency and amplitude measures. The study suggested that otolith

dysfunction is more common in children with SNHL, particularly in those with vestibular malformations.

Guma et al. (2024) evaluated cVEMP and oVEMP responses in 51 children (mean age: 3.3 years) using 500 Hz tone burst stimuli presented through the Eclipse evoked potential system. oVEMP responses were absent in 47.69% of ears in the hearing-impaired group, and vestibular abnormalities increased with greater hearing loss severity. The study suggested that otolithic dysfunction commonly accompanies childhood SNHL, particularly in severe-to-profound hearing loss.

Taken together, the available evidence supports the presence of utricular dysfunction across different SNHL populations. Reduced response rates, elevated thresholds, and decreased amplitudes are among the most consistently reported oVEMP findings, whereas latency changes appear to vary across studies. Several studies have also suggested that greater hearing loss severity may be associated with increased oVEMP abnormalities, although this relationship is not consistently reported across all age Studies. Overall, these findings support the clinical usefulness of oVEMP as part of a comprehensive vestibular evaluation, particularly in children, cochlear implant candidates, and individuals with sudden or profound SNHL.

2.3 Masseter Vestibular Evoked Myogenic Potentials (mVEMP) in Clinical and Auditory Populations

The masseter vestibular evoked myogenic potential (mVEMP) is a newer electrophysiological measure that evaluates the vestibulo-trigeminal reflex pathway. While cVEMP targets the sacculo-collic pathway, mVEMP captures vestibular projections to the trigeminal motor nucleus and the masseter muscle. Compared to cVEMP and oVEMP, literature

related to mVEMP is still limited. However, recent studies suggest that mVEMP may provide additional information regarding both peripheral and central vestibular pathway.

Several studies have investigated the recording characteristics and reliability of mVEMP in healthy adults. Deriu et al. (2007) were among the first to describe sound-evoked mVEMP responses in normal-hearing individuals using click stimuli. Later studies by Vignesh et al. (2021) further supported the reproducibility of mVEMP recordings and established normative latency, amplitude, and asymmetry ratio values. Studies by Neupane et al. (2023) and Nagarajan et al. (2024) also showed that mVEMP findings may vary depending on the type of stimulus used.

Abnormal mVEMP findings have been reported in several neurological disorders associated with brainstem dysfunction. Magnano et al. (2014) evaluated vestibulo-masseteric reflexes in 60 individuals with multiple sclerosis and observed abnormalities in 62.1% of participants. The study also reported significantly prolonged p11 latencies in the multiple sclerosis group compared to controls, although amplitude measures did not differ significantly. The authors suggested that vestibulo-trigeminal pathway testing may help identify early brainstem dysfunction in multiple sclerosis.

Similarly, Sangu Srinivasan et al. (2023) assessed cVEMP, oVEMP, and mVEMP responses in 45 individuals with multiple sclerosis and reported abnormal mVEMP findings in 82.22% of participants, which was higher than the abnormalities observed for cVEMP and oVEMP. Absent responses were the most common finding, followed by delayed latencies and reduced amplitudes. The authors concluded that mVEMP may be particularly sensitive in identifying vestibulo-trigeminal pathway involvement in multiple sclerosis.

Magnano et al. (2016) Further evaluated brainstem reflexes in individuals with multiple sclerosis over a follow-up period of approximately 15 months. Brainstem reflex abnormalities

increased from 82.2% at baseline to 91.1% during follow-up assessment, with significant worsening observed particularly in vestibulo-masseteric reflex findings. The study suggested that vestibulo-masseteric reflex testing may detect progression of brainstem dysfunction even when clinical and MRI findings remain stable.

mVEMP abnormalities have also been reported in Parkinson's disease. de Natale et al. (2015) evaluated cVEMP, oVEMP, and mVEMP responses in 24 individuals with Parkinson's disease and 24 age-matched controls. The study reported mVEMP abnormalities in 66.7% of individuals with Parkinson's disease, compared to a much lower abnormality rate in controls. Absence of responses was the most frequently observed abnormality, and the number of altered VEMP responses showed correlation with clinical measures related to postural instability and REM sleep behaviour disorder. The authors suggested that VEMP abnormalities may reflect underlying brainstem degeneration in Parkinson's disease.

Similarly, Liu et al. (2019) assessed cVEMP, oVEMP, and mVEMP responses in 30 individuals with amyotrophic lateral sclerosis, including patients with and without brainstem involvement. Abnormal mVEMP findings were observed in 40% of participants, while cVEMP and oVEMP abnormalities were reported in 67% and 45% of participants, respectively. The ALS group showed delayed VEMP latencies and interpeak latency differences. Patients with brainstem involvement had more VEMP abnormalities, indicating that these measures may reflect brainstem dysfunction in ALS.

de Natale et al. (2018) Further investigated cVEMP, oVEMP, and mVEMP responses in individuals with idiopathic REM sleep disorder. Abnormal findings were observed in 45% for cVEMP, 50% for oVEMP, and 65% for mVEMP. Significant reduction in amplitudes was noted across all three VEMPs, while delayed p11 latency was observed in mVEMP recordings. Similarly,

Puligheddu et al. (2019) reported higher mVEMP abnormality rates in individuals with isolated REM sleep behaviour disorder compared to controls, with significantly prolonged p11 latency and reduced amplitudes in mVEMP recordings. These findings suggest that mVEMP may be sensitive to early brainstem dysfunction even before overt neurological conditions become clinically evident. Taken together, these studies indicate that mVEMP may be useful in identifying vestibulo-trigeminal and brainstem pathway dysfunction in various neurological disorders.

Apart from neurological disorders, mVEMP has also been explored in peripheral vestibular disorders. Gugle & Neupane (2025) investigated narrowband CE-Chirp evoked mVEMP responses in 22 ears with definite Meniere's disease and compared them with 22 normal-hearing ears across 500 Hz, 1000 Hz, and 2000 Hz stimulation frequencies. The study reported significantly reduced p11–n21 amplitudes in the Meniere's disease group across all frequencies ($p < 0.05$), while latency differences were not statistically significant. The authors suggested that these findings indicate possible vestibulo-trigeminal pathway involvement in definite Meniere's disease.

Comacchio et al. (2025) evaluated 500 Hz tone burst evoked mVEMP responses in individuals with vestibular neuritis and reported good agreement between mVEMP and cVEMP findings. In some cases, mVEMP responses were preserved despite absent cVEMPs, suggesting greater robustness of mVEMP in certain vestibular lesions. The authors concluded that mVEMP may provide complementary information regarding vestibulo-trigeminal and inferior vestibular nerve dysfunction.

Only a limited number of studies have investigated mVEMP findings in auditory disorders and sensorineural hearing loss populations. Deriu et al. (2007), while investigating the origin of sound-evoked masseter responses, included five individuals with profound hearing loss, including

four congenital and one acquired case. Bilaterally present vestibular masseter responses were obtained despite severe hearing loss. The study suggested that the early mVEMP component may primarily reflect vestibular rather than cochlear activation, while later response components may have auditory contributions.

Kalaiyarasan and Sinha (2024)evaluated 500 Hz tone burst evoked mVEMP and cVEMP responses in 20 individuals with auditory neuropathy and 20 age- and gender-matched healthy adults. Most individuals with auditory neuropathy showed absent mVEMP responses, with ipsilateral and contralateral absence observed in 60% and bilateral absence in 50% of participants. A significant positive correlation was observed between rectified amplitudes of mVEMP and cVEMP ($p < 0.05$). The authors suggested impaired vestibulo-masseteric and sacculo-collic reflex pathway in individuals with auditory neuropathy and recommended inclusion of vestibular assessment as part of routine evaluation.

Similarly, Sarkar and Sinha (2023) evaluated mVEMP findings in individuals with severe-to-profound SNHL and compared them with normal hearing adults. Reduced response rates along with delayed p11 and n21 latency findings, were observed in the SNHL group. Although amplitude reduction was not statistically significant, clinically reduced amplitudes and prolonged latency trends were noted in hearing-impaired participants. The authors suggested that these findings may indicate vestibulo-trigeminal pathway involvement in individuals with severe-to-profound SNHL.

Taken together, the available literature suggests that mVEMP may serve as a useful tool for assessing vestibulo-trigeminal pathway function in neurological, vestibular, and auditory disorders. However, compared to cVEMP and oVEMP, studies investigating mVEMP findings in individuals with sensorineural hearing loss remain limited. Further research is needed to better understand the role of mVEMP in identifying vestibular involvement associated with SNHL.

Chapter 3

Method

The study was conducted with an aim of assessing the sacculocollic, otolithocular and vestibulomasseteric reflex pathways in individuals with moderate to profound sensorineural hearing loss. To achieve the aim, cervical VEMP (cVEMP), ocular VEMP (oVEMP), and masseter VEMP (mVEMP) were recorded. The response patterns, latencies, and amplitudes of VEMP tests were compared between SNHL patients and age and gender-matched normal hearing individuals.

Participants

The study included two groups of participants, Group I, consisting of adults with bilateral moderate to profound SNHL, and Group II, comprising age- and gender-matched adults with normal hearing sensitivity.

Group I

Twenty adults with bilateral moderate-to-profound SNHL were enrolled in the study, comprising 10 males and 10 females, with ages ranging from 18 to 55 years (mean age = 40.05 years; SD = 10.10 years). The degree of hearing loss was confirmed through pure-tone audiometry, with air-conduction and bone-conduction thresholds measured at octave frequencies ranging from 250 Hz to 8000 Hz.

Group II

The control group consisted of twenty age- and gender-matched adults, comprising 10 males and 10 females, with a mean age of 39.75 years (SD = 10.41 years). All control participants demonstrated normal hearing sensitivity (≤25 dB HL across octave frequencies 250–8000 Hz) and normal middle-ear function.

Participant selection criteria for group I

1. Participants had a confirmed diagnosis of bilateral moderate to profound sensorineural hearing loss.
2. Individuals with a Type A or As tympanogram and present or absent middle ear reflexes, based on the degree of hearing loss, were included.
3. Participants did not have any evidence of vestibular diseases such as Ménière's disease, labyrinthitis, or neuritis.
4. Individuals did not have systemic medical conditions such as diabetes mellitus or hypertension.

Exclusion Criteria for Group I

1. Participants with conductive or mixed hearing loss were excluded from the study.
2. Individuals with a prior diagnosis of vestibular disorders, including recurrent vertigo, clinically confirmed benign paroxysmal positional vertigo (BPPV), or Ménière's disease, were not eligible for the study.
3. Participants with a history of neurological disease, head injury, or central vestibular disorder were excluded.
4. Individuals currently taking medications with known vestibulotoxic or ototoxic effects, such as aminoglycosides or high-dose loop diuretics, were not included.
5. Participants with medical or psychiatric conditions that could interfere with VEMP testing or informed consent, were excluded from the study.
6. Individuals who could not maintain the required muscle contraction during testing were also excluded.
7. Participants with neck pain and jaw pain were excluded from the study.

Participants Selection Criteria for Group II

1. Individuals with normal hearing sensitivity, defined as pure-tone air-conduction thresholds of 25 dB HL or better at octave frequencies from 250 to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction in both ears, were included.
2. All participants with normal middle ear function, evidenced by a Type A or As tympanogram and presence of ipsilateral and contralateral acoustic reflexes, were included.
3. Individuals with no prior history of auditory, vestibular, or neurological disorders were considered eligible for participation.

Exclusion Criteria for Group II

1. Participants presenting with any degree of sensorineural, conductive, or mixed hearing loss, defined as thresholds greater than 25 dB HL at any octave frequency between 250 and 8000 Hz, were excluded from the study.
2. Participants with a current or past history of vestibular disorders, such as benign paroxysmal positional vertigo (BPPV) or Ménière's disease, or those reporting persistent imbalance, were excluded.
3. Individuals with a history of neurological disorders or prior significant head injury were not included.
4. Participants who were currently using medications known to be vestibulotoxic or ototoxic were excluded from the study.
5. Individuals with any medical, physical, or cognitive condition that could interfere with reliable VEMP testing. for example, difficulty following task instructions or maintaining the required level of muscle activation, were not eligible for participation.
6. Participants with neck pain and jaw pain were excluded from the study.

Ethical Considerations

The study was approved by the Institutional Ethical Committee of the All India Institute of Speech and Hearing (AIISH), Mysuru (Ref: SH/IRB/M.4/AUD.04/2025-26), and followed the bio-behavioural ethical guidelines outlined by Venkatesan and Basavaraj (2009). All participants were recruited on a voluntary basis. Before data collection, written informed consent was obtained after a detailed explanation of the study's purpose, procedures, and any potential risks.

Test Environment

All experimental recordings were conducted in an acoustically and electrically shielded room within the Department of Audiology at the All India Institute of Speech and Hearing (AIISH), Mysuru. Ambient noise levels were maintained within the permissible limits specified by the American National Standards Institute (ANSI S3.1–1991) for audiometric testing.

Instrumentation

Diagnostic Audiometer

The diagnostic audiometric evaluation was done using a GSI AudioStar Pro diagnostic audiometer (Grason-Stadler [GSI], USA). ER-3A insert earphones were used for air conduction testing, while a Radioear B-71 bone vibrator was used for bone conduction testing. The audiometer was calibrated in accordance with ANSI S3.6-2018 standards to ensure accurate and reliable test results.

Immittance Meter

Immittance testing was performed using a GSI TympStar Pro immittance meter (Grason-Stadler [GSI], USA). The instrument was used to record tympanometry and acoustic reflexes.

VEMP Recording System

VEMP recordings were obtained using the Neuro Audio Evoked Potential System (Version 2010), manufactured by Neurosoft, Ivanovo, Russia. Surface cup electrodes were used for recording, and ER-3A insert earphones were used for stimulus presentation.

Procedure

Cervical Vestibular Evoked Myogenic Potentials (cVEMP)

The participants were seated comfortably in a straight-backed chair and instructed to rotate the head contralaterally to the side of stimulation to activate the sternocleidomastoid (SCM) muscle. This ensured adequate tonic muscle contraction, which is essential for recording robust cVEMP responses. Before electrode placement, the skin was cleaned thoroughly using an alcohol swab to remove surface oils, followed by gentle abrasion with Nuprep gel to reduce electrode–skin impedance. After skin preparation, disposable Ag/AgCl surface-cup electrodes were applied with Ten20 conductive paste. The non-inverting (active) electrode was placed over the upper one-third of the SCM muscle on the side of stimulation. The inverting (reference) electrode was positioned at the sternoclavicular junction of the same side, and the ground electrode was placed at the forehead (Fpz). Electrode impedances were checked, and absolute electrode impedance was maintained below 5 kΩ, and inter-electrode differences were maintained within 2 kΩ.

Acoustic stimuli consisted of 500 Hz short tone bursts delivered monaurally through ER-3A insert earphones. The detailed stimulus and acquisition parameters are given in Table 3.1.

Table 3.1

Stimulus and Acquisition Parameters for Cervical VEMPs (cVEMP)

Stimulus Parameters		**Acquisition Parameters**	
Stimulus type	Tone bursts	**Analysis time**	100 ms (10 ms pre-stimulus)
Frequency	500 Hz	**Filter settings**	10–1500 Hz

Intensity	125 dB peSPL	**No. of sweeps**	200
Gating	Blackman window	**Amplifier gain**	5000
Stimulus duration	2–0–2 ms	**No. of channels**	1
Polarity	Rarefaction	**Electrode montage non-inverting:**	Upper one-third of the SCM
Repetition rate	5.1/s	**Inverting:**	Sternoclavicular junction;
Stimulation mode	Monaural (Ipsilateral)	**Ground:**	forehead
Transducer	Insert earphones	**Artifact rejection**	± 800 μV

Ocular Vestibular Evoked Myogenic Potentials (oVEMP)

Participants were seated comfortably and instructed to gaze upward at a fixed point approximately 30° above the horizontal plane to activate the inferior oblique muscles. This upward gaze was maintained throughout data collection. The skin below each eye and on the cheek was cleaned with an alcohol swab, followed by Nuprep gel to ensure good electrode contact. The active (non-inverting) surface cup electrode was placed using Ten20 conductive paste, approximately 1 cm below the lower eyelid (infraorbital ridge) contralateral to the side of stimulation. The reference (inverting) electrode was placed about 1–2 cm below the active electrode on the cheek, and the ground electrode was placed on the forehead (Fpz). All electrode impedances were kept below 5 kΩ, with inter-electrode differences not exceeding 2 kΩ. The detailed stimulus and acquisition parameters are given in Table 3.2.

Table 3.2

Stimulus and Acquisition Parameters for Ocular VEMPs (oVEMP)

Stimulus Parameters		**Acquisition Parameters**	
Stimulus type	Tone bursts	**Analysis time**	100 ms (10 ms pre-stimulus)

Frequency	500 Hz	**Filter settings**	0.1–1000 Hz
Intensity	125 dB peSPL	**No. of sweeps**	200
Gating	Blackman window	**Amplifier gain**	5000
Stimulus duration	2–0–2 ms	**No. of channels**	1
Polarity	Rarefaction	**Electrode montage Non-inverting:**	Inferior Oblique Muscle
Repetition rate	5.1/s	**Inverting:**	1–2 cm below the active electrode
Stimulation mode	Monaural (contralateral)	**Ground:**	forehead
Transducer	Insert earphones	**Artifact rejection**	±40 μV

Recording of Masseter Vestibular Evoked Myogenic Potentials (mVEMP)

Participants were seated upright and instructed to clench their teeth to contract the masseter muscles bilaterally. Care was taken to maintain consistent clenching effort throughout the recording. The skin over the masseter region was cleaned with an alcohol swab and slightly abraded using Nuprep gel. The non-inverting (active) electrode was positioned over the belly of the masseter muscle on the side of stimulation using Ten20 conductive paste, while the inverting (reference) electrode was placed at the arch of zygomatic bone. The ground electrode was fixed at the mid-forehead (Fpz). Electrode impedance was maintained below 5 kΩ, and symmetry between the two sides was ensured to minimize recording bias. The detailed stimulus and acquisition parameters are presented in Table 3.3.

Table 3.3

Stimulus and Acquisition Parameters for masseter VEMPs(mVEMP).

Stimulus Parameters	Acquisition Parameters

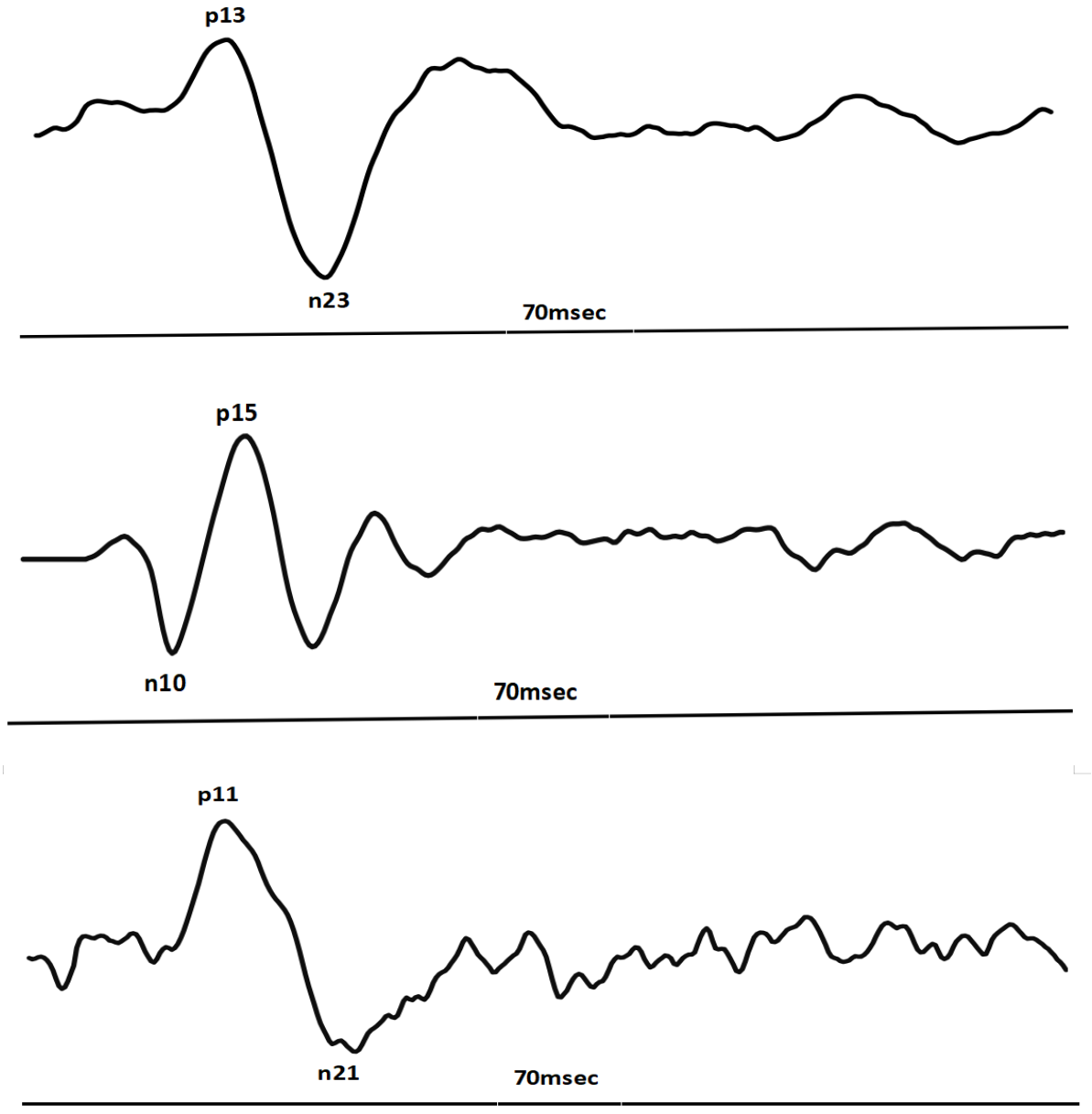
Stimulus type	Tone bursts	**Analysis time**	100 ms (10 ms pre-stimulus)
Frequency	500 Hz	**Filter settings**	0.1–3000 Hz
Intensity	125 dB peSPL	**No. of sweeps**	200
Gating	Blackman window	**Amplifier gain**	5000
Stimulus duration	2–0–2 ms	**No. of channels**	1
Polarity	Rarefaction	**Electrode montage Non-inverting:**	Masseter Muscle
Repetition rate	5.1/s	**Inverting:**	Zygomatic arch
Stimulation mode	Monaural (ipsilateral)	**Ground:**	forehead
Transducer	Insert earphones	**Artifact rejection**	± 800 µV

Data Analysis

The recorded cVEMP, oVEMP, and mVEMP waveforms were first visually inspected to check whether the responses were clear and reproducible. Only those waveforms that showed good repeatability were taken for further analysis. After confirming the response, the peaks were identified and marked as p13 and n23 for cVEMP, n10 and p15 for oVEMP, and p11 and n21 for mVEMP as shown in Figure 3.1. Based on these marked peaks, latency, peak-to-peak rectified amplitude, and asymmetry ratio were calculated for each response. The response rate was calculated as the percentage of participants with clear, reproducible waveforms.

Figure 3.1

cVEMP, oVEMP, and mVEMP waveforms showing the marked peaks used for analysis.



Statistical analysis

All data were entered into Microsoft Excel and later exported to SPSS software (Version 25.0, IBM Corp.) for statistical analysis.

- Descriptive statistics, including mean and standard deviation, were done for all parameters.
- The normality of data distribution was assessed using the Shapiro–Wilk test.
- Based on the overall normal distribution of the data, parametric statistical tests were considered appropriate for further analysis.
- A paired samples t-test was used to compare the right and left ears for each VEMP type.
- The McNemar test was used to compare cVEMP, oVEMP and mVEMP response rates in the SNHL group and control group
- Independent samples t-tests were used to compare latency, amplitude, and asymmetry ratio between the SNHL group and the healthy control group based on the distribution of the averaged data.
- Bivariate correlation analysis was carried out to examine the relationship between cVEMP, oVEMP, and mVEMP latency and amplitude measures.
- Pearson's correlation coefficient was used for normally distributed data, while Spearman's rank correlation was used for non-normally distributed data.
- A p-value of less than 0.05 was considered statistically significant.

Chapter-4

Results

The aim of the study was to compare the cervical, ocular, and masseter vestibular evoked myogenic potentials (cVEMP, oVEMP, and mVEMP) in adults with bilateral moderate to profound sensorineural hearing loss. Cervical, ocular, and masseter VEMPs (cVEMP, oVEMP, and mVEMP) were recorded and analysed. Parameters, including response rate, latency, amplitude, and asymmetry ratio were assessed to evaluate group differences. In addition, correlational analyses was also done to investigate associations among these measures.

4.1. Response rate of cVEMP, oVEMP, and mVEMP in individuals with bilateral moderate to profound sensorineural hearing loss

The response rates of cervical, ocular, and masseter vestibular evoked myogenic potentials (cVEMP, oVEMP, and mVEMP) were analysed in both normal-hearing individuals and adults with bilateral moderate-to-profound sensorineural hearing loss (SNHL), to examine the presence of reproducible responses across different VEMPs, as seen in Table 4.1.

Table 4.1

Response rates of cVEMP, oVEMP, and mVEMP across right and left ears in normal-hearing and SNHL groups.

VEMP Test	Normal Group (Present/20)	SNHL Group (Present/20)	Fisher's Exact Test (p-value)
Right cVEMP	20	18	0.487
Left cVEMP	20	18	0.487
Right oVEMP	18	15	0.407
Left oVEMP	18	15	0.407
Right mVEMP	19	11	0.008
Left mVEMP	19	11	0.008

Note. cVEMP = cervical vestibular evoked myogenic potential; oVEMP = ocular vestibular evoked myogenic potential; mVEMP = masseter vestibular evoked myogenic potential; SNHL = sensorineural hearing loss. Values represent the number of ears showing reproducible responses out of 20 ears in each group. Fisher's Exact Test was used to compare response rates between the normal-hearing and SNHL groups. A p-value < 0.05 was considered statistically significant.

In the normal-hearing group, cVEMP responses were present bilaterally in all participants, resulting in a 100% response rate (40/40 ears). oVEMP responses were obtained in 90% of participants, corresponding to 36 out of 40 ears, while mVEMP responses were obtained in 95% of participants, corresponding to 38 out of 40 ears, as seen in Table 4.1. The absent responses were minimal and distributed similarly across both ears.

In the SNHL group, response rates across all three VEMP tests were comparatively lower (Table 4.1). cVEMP responses were present in 90% of participants, corresponding to 36 out of 40 ears. oVEMP responses were present in 75% of participants, corresponding to 30 out of 40 ears, while mVEMP responses were present in only 55% of participants, corresponding to 22 out of 40 ears. Despite the variation in overall response rates, the distribution of responses across the right and left ears remained similar for all three tests.

Comparison between the normal-hearing and SNHL groups showed lower response rates in the SNHL group across all three VEMP tests. Chi-square test showed no significant difference between the groups for cVEMP and oVEMP responses ($p > 0.05$). However, a significant reduction in mVEMP response rate was observed in the SNHL group compared to the normal-hearing group

(p = 0.008), as seen in Table 4.1. The individual and averaged cVEMP, oVEMP and mVEMP waveforms are present in Figures 4.1 and 4.2, for normals and SNHL, respectively.

Figure 4.1.

Individual and averaged waveforms of cVEMP, oVEMP, and mVEMP in the normal-hearing group. The upper panel shows the individual waveforms, while the lower panel shows the averaged waveforms with identifiable peaks for each VEMP modality.

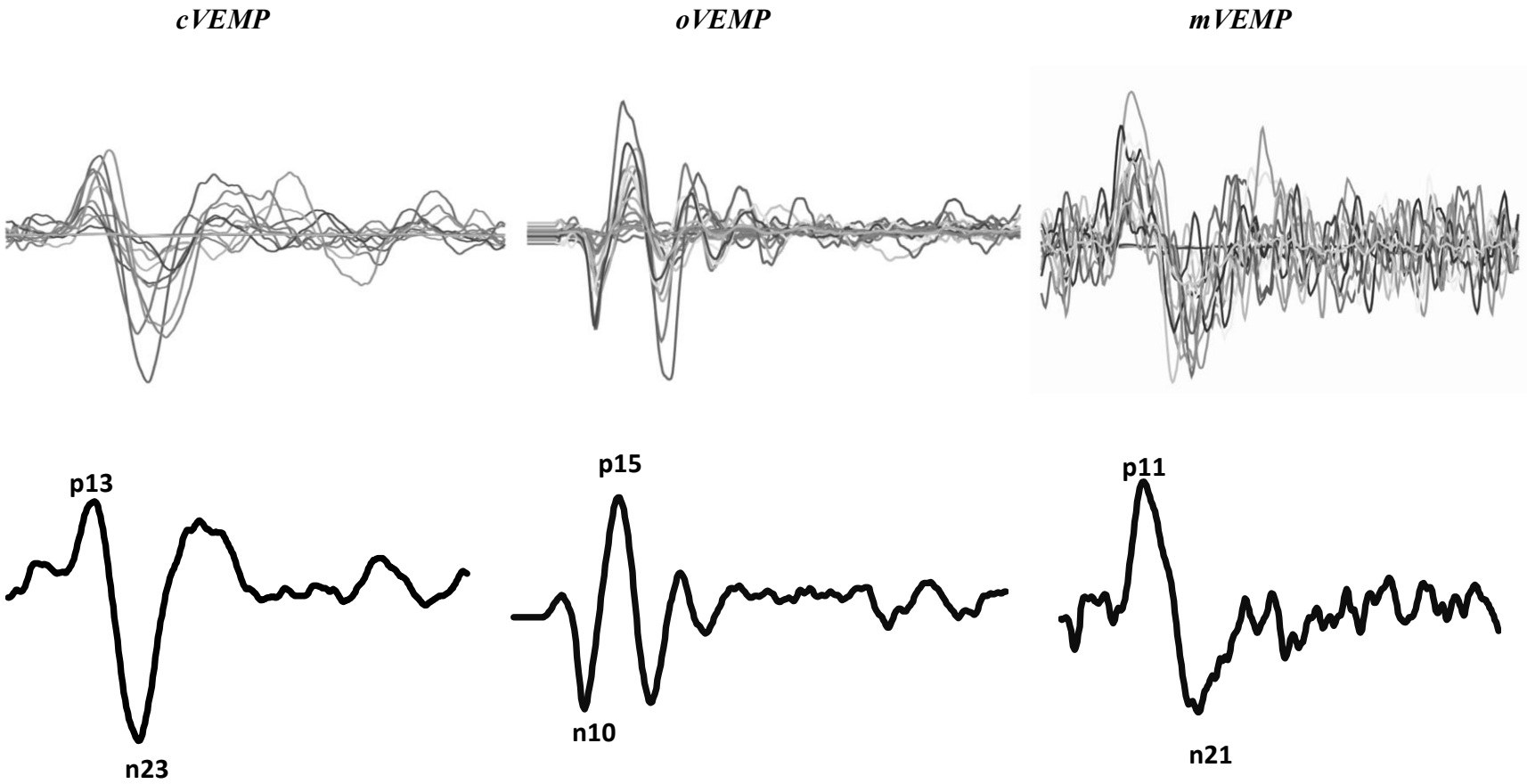
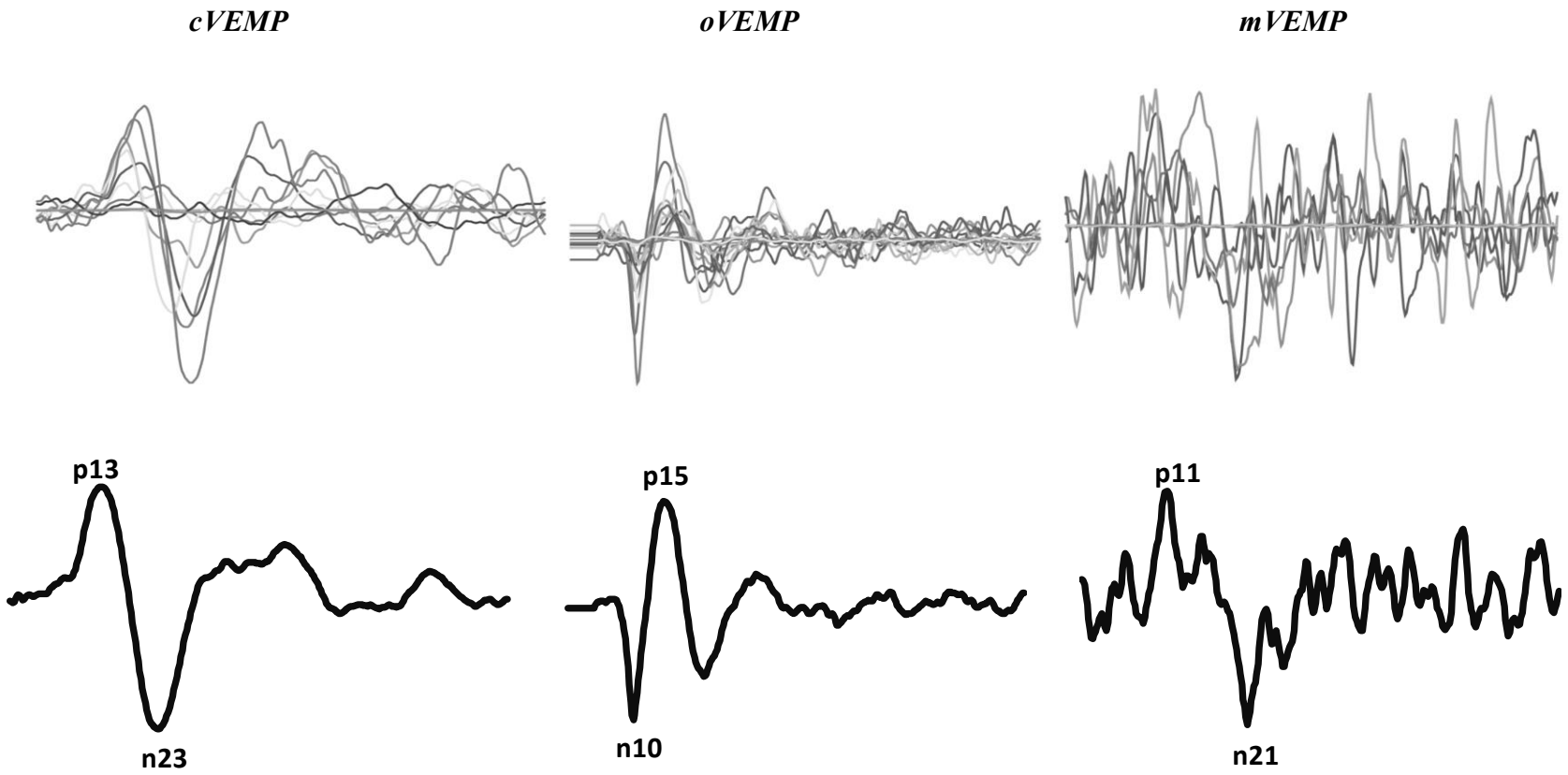


Figure 4.2

Individual and averaged ACCI waveforms of cVEMP, oVEMP, and mVEMP in the SNHL group. The upper panel shows the individual waveforms, while the lower panel shows the averaged waveforms with identifiable peaks for each VEMP.



Note. cVEMP = cervical vestibular evoked myogenic potential; oVEMP = ocular vestibular evoked myogenic potential; mVEMP = masseter vestibular evoked myogenic potential; SNHL = sensorineural hearing loss; p13 and n23 represent the positive and negative peaks of cVEMP, respectively; n10 and p15 represent

the negative and positive peaks of oVEMP, respectively; p11 and n21 represent the positive and negative peaks of mVEMP, respectively.

In the SNHL group, the cVEMP and oVEMP waveforms also showed biphasic response patterns similar to those seen in the normal-hearing group. However, the mVEMP waveforms appeared less clear and showed more variation across participants. The averaged waveforms also reflected this variation, especially for mVEMP responses. The individual and averaged ACCI waveforms for the SNHL group are shown in Figure 4.2.

4.2. Latency and amplitude parameters of cVEMP, oVEMP, and mVEMP between the SNHL group and the healthy group.

The descriptive statistics for latency, rectified amplitude, and asymmetry ratio parameters of cVEMP, oVEMP, and mVEMP in the normal-hearing and SNHL groups were done.

Table 4.2 presents the descriptive statistics for latency parameters across both groups. Latency values were largely comparable between the normal-hearing and SNHL groups, with both ear showing minimal variation. mVEMP (p11) showed slightly higher values in the SNHL group. The mean latency values are illustrated in Figure 4.3, supporting the above findings.

Table 4.2

Descriptive Statistics of Latency(msec) VEMPs in Normal-Hearing Group and SNHL Group.

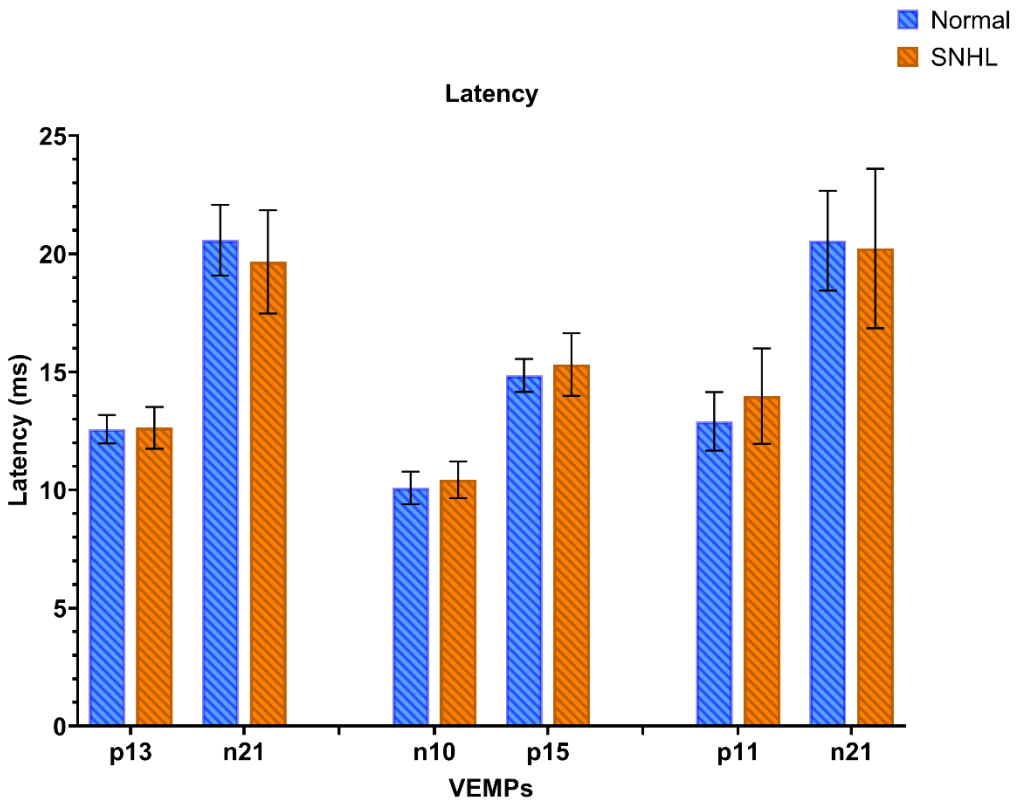
	Normal				**SNHL**			
	Right		**Left**		**Right**		**Left**	
Parameter	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
p13 Latency	12.64	0.815	12.52	0.851	12.78	1.127	12.48	0.913
n23 Latency	20.81	1.8414	20.340	1.5014	19.622	3.3588	19.700	1.5878

n10 Latency	10.12	0.655	10.061	0.8417	10.31	0.828	10.480	0.8257
p15 Latency	14.822	0.7084	14.872	0.8628	15.087	1.4564	15.513	1.3016
p11 Latency	12.853	1.2786	12.91	1.304	14.018	1.9182	13.94	2.189
n21 Latency	20.489	2.2326	20.565	2.1216	20.036	3.1822	20.418	3.6521

Note. cVEMP = cervical vestibular evoked myogenic potential; oVEMP = ocular vestibular evoked myogenic potential; mVEMP = masseter vestibular evoked myogenic potential; SD = standard deviation; p13 and n23 represent cVEMP peaks; n10 and p15 represent oVEMP peaks; p11 and n21 represent mVEMP peaks.

Figure 4.3

Bar graph representation of mean latency values with standard deviation for cVEMP, oVEMP, and mVEMP in the normal-hearing and SNHL groups. The figure shows the comparison of latency values across the two groups for each VEMP parameter.



Note. SNHL = Sensorineural hearing loss

The rectified amplitude values of cVEMP, oVEMP, and mVEMP across both groups are presented in Table 4.3. Amplitude values were lower in the SNHL group across all three VEMP tests, with the greatest reduction seen in mVEMP responses. These findings are further supported by the bar graph representations shown in Figure 4.4.

Table 4.3

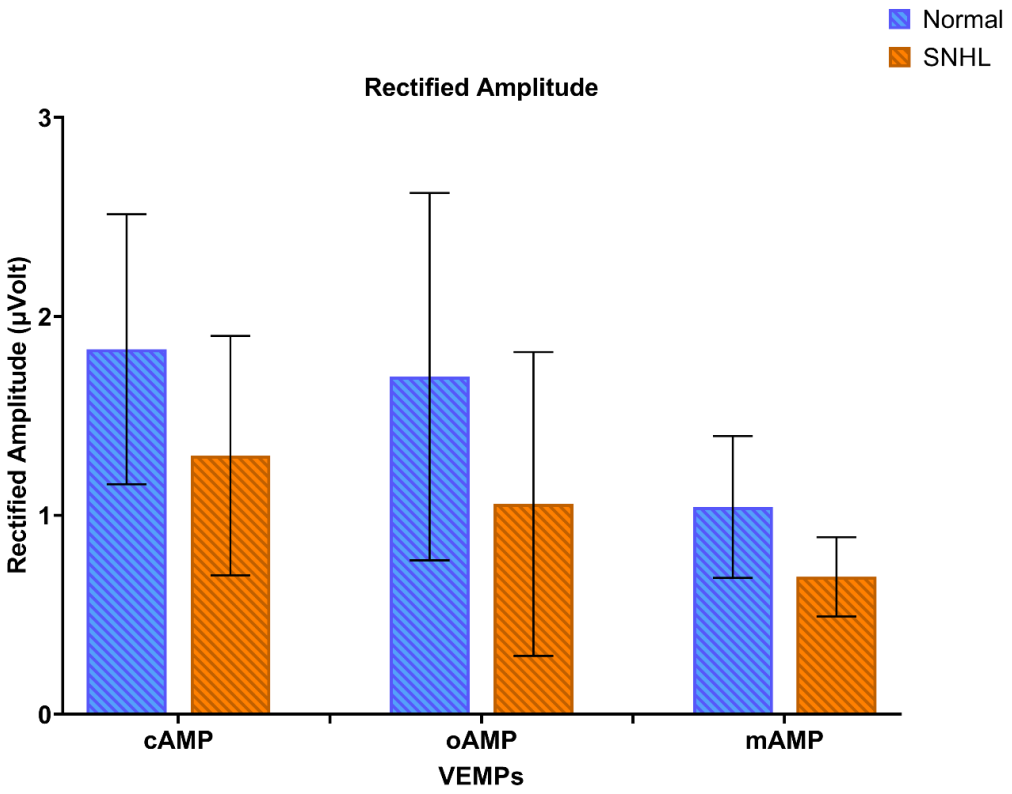
Descriptive Statistics of Rectified Amplitude(μV) in the Normal Hearing and SNHL Groups.

	Normal				**SNHL**			
	Right		**Left**		**Right**		**Left**	
Parameter	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
cVEMP Amplitude	1.875	0.762	1.795	0.634	1.228	0.636	1.312	0.725
oVEMP Amplitude	1.522	0.9687	1.872	1.265	1.253	0.901	0.907	0.724
mVEMP Amplitude	0.995	0.344	1.09	0.407	0.745	0.246	0.636	0.201

Note. SD = standard deviation; Mean values are given in μV (microvolt).

Figure 4.4.

Bar graph representation of mean rectified amplitude values with standard deviation for cVEMP, oVEMP, and mVEMP in the normal-hearing and SNHL groups. The figure shows the comparison of rectified amplitude values across the two groups for each VEMP parameter.



Note. SNHL = sensorineural hearing loss; error bars represent standard deviation., cAMP refers to rectified amplitude of cVEMP, oAMP refers to rectified amplitude of oVEMP, and mAMP refers to rectified amplitude of mVEMP.

Both groups demonstrated similar asymmetry ratio patterns across all three VEMP tests, with only minor differences observed between them. These values are detailed in Table 4.4 and visually represented in Figure 4.5.

Table 4.4

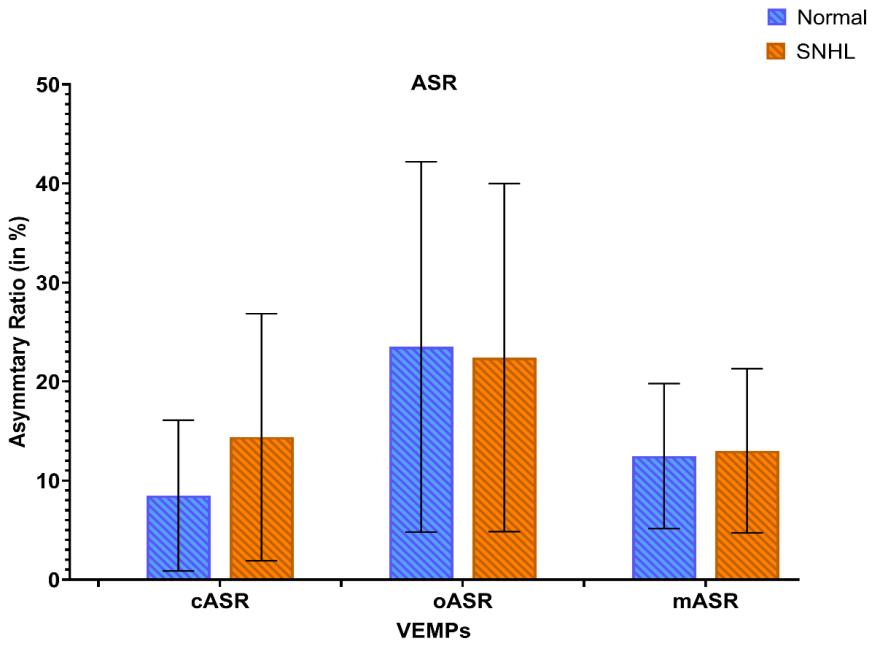
Descriptive Statistics of VEMP Asymmetry Ratio in the Normal Hearing and SNHL Groups.

	Normal		SNHL	
Parameter	**Mean**	**SD**	**Mean**	**SD**
cVEMP Asymmetry Ratio	8.48	7.618	14.371	12.471
oVEMP Asymmetry Ratio	23.483	18.694	22.407	17.575
mVEMP Asymmetry Ratio	12.468	7.326	13.009	8.282

Note. SD = standard deviation.

Figure 4.5.

Bar graph representation of mean asymmetry ratio values with standard deviation for cVEMP, oVEMP, and mVEMP in the normal-hearing and SNHL groups. The figure shows the comparison of asymmetry ratio values across the two groups for each VEMP parameter.



Note. SNHL, sensorineural hearing loss. cASR refers to Asymmetry ratio of cVEMP, oASR refers to Asymmetry ratio of oVEMP, and mASR refers to Asymmetry ratio of mVEMP.

A paired-samples t-test was performed to compare latency and amplitude values between the right and left ears for cVEMP, oVEMP, and mVEMP among the studied participants. The results showed no statistically significant differences between the right and left ears for any latency or amplitude parameter across all three VEMP modalities ($p > 0.05$), as shown in Table 4.5. This indicates that responses from both ears were similar across participants. Since no significant interaural differences were observed, the values from the right and left ears were averaged for each participant and used for further statistical analysis.

Table 4.5

Paired sample t-test comparison of right and left ear latency and rectified amplitude parameters of cVEMP, oVEMP, and mVEMP in the normal-hearing and SNHL groups.

Pairs	Right ear and left ear Pair	t Value	Sig. (2-tailed)
1	p13 Latency	1.148	0.259
2	n23 Latency	0.579	0.566
3	cVEMP Rectified Amplitude	0.427	0.672
4	n10 Latency	-0.22	0.827
5	p15 Latency	-1.142	0.262
6	oVEMP Rectified Amplitude	-0.237	0.814
7	p11 Latency	-0.254	0.802
8	n21 Latency	-1.089	0.285
9	mVEMP Rectified Amplitude	-0.265	0.793

Note. cVEMP = cervical vestibular evoked myogenic potential; oVEMP = ocular vestibular evoked myogenic potential; mVEMP = masseter vestibular evoked myogenic potential; $p < 0.05$ indicates statistically significant difference.

Descriptive statistical analysis was performed on the averaged latency, amplitude, and asymmetry ratio values of cVEMP, oVEMP, and mVEMP in both the normal-hearing and SNHL

groups. The detailed mean and standard deviation values for all the parameters are given in Tables 4.6.

Table 4.6 *Descriptive Statistics of Averaged VEMP Parameters in Normal Group*

VEMP	p13	n23	cVEMP Rectified Amplitude	cVEMP Asymmetry Ratio	n10	p15	oVEMP Rectified Amplitude	oVEMP Asymmetry Ratio	p11	n21	mVEMP Rectified amplitude	mVEMP Asymmetry Ratio
						Normal						
Mean	12.57	20.57	1.83	8.48	10.09	14.84	1.69	23.48	12.9	20.55	1.03	12.46
SD	0.6	1.49	0.67	7.61	0.68	0.69	0.92	18.69	1.23	2.11	0.35	7.32
						SNHL						
Mean	12.63	19.66	1.3	14.37	10.43	15.31	1.05	22.4	13.97	20.22	0.69	13.01
SD	0.88	2.18	0.6	12.47	0.77	1.32	0.76	17.57	2.01	3.38	0.19	8.28

Note. SD = standard deviation; p13 and n23 = cVEMP peaks; n10 and p15 = oVEMP peaks; p11 and n21 = mVEMP peaks. Latency values are in milliseconds (ms) and amplitude values in microvolts (µV).

An independent sample t-test was carried out to compare the averaged latency, rectified amplitude, and asymmetry ratio values of cVEMP, oVEMP, and mVEMP between the normal-hearing and SNHL groups. Latency values showed no significant differences across cVEMP, oVEMP, and mVEMP between the groups. However, cVEMP and mVEMP amplitude values were significantly lower in the SNHL group compared to the normal-hearing group, while oVEMP amplitude showed no significant difference. Regarding asymmetry ratio, a significant difference was observed only for oVEMP, whereas cVEMP and mVEMP asymmetry ratios did not differ significantly between the groups. The detailed results are presented in Table 4.7.

Table 4.7

Independent sample t-test comparison of VEMP parameters between normal-hearing and SNHL groups

VEMP	P1 Latency *(t, p)*	N1 Latency *(t, p)*	Amplitude *(t, p)*	Asymmetry Ratio *(t, p)*
cVEMP	t = 0.208, p = 0.836	t = 1.073, p = 0.290	t = 2.516, p = 0.017	t = 1.544, p = 0.131
oVEMP	t = 1.565, p = 0.126	t = 1.321, p = 0.194	t = 0.167, p = 0.869	t = 2.095, p = 0.045
mVEMP	t = 1.954, p = 0.058	t = 0.449, p = 0.656	t = 2.972, p = 0.006	t = 0.221, p = 0.826

Note. t represents the t-value obtained from the independent sample t-test, p represents the probability value, and df represents the degrees of freedom. Degrees of freedom (df) = 38 for all comparisons. $p < 0.05$ indicates a statistically significant difference.

4.3. Correlation between cVEMP, oVEMP, and mVEMP latency and amplitude parameters in healthy and SNHL group

To study the correlation between the VEMPs Bivariate correlation analysis was done in the normal-hearing group. The analysis included latency, rectified amplitude, and asymmetry ratio measures of all three VEMP tests.

In the normal-hearing group, most correlations among cVEMP, oVEMP, and mVEMP parameters were not statistically significant ($p > 0.05$), suggesting no clear relationship among these measures. This was observed for latency, rectified amplitude, and asymmetry ratio values. However, a significant positive correlation was found between cVEMP rectified amplitude and and oVEMP asymmetry ratio, between cVEMP asymmetry ratio and mVEMP rectified amplitude, and between p13 latency and mVEMP asymmetry ratio. A significant negative correlation was also observed between p15 latency and mVEMP asymmetry ratio. The detailed correlation results for the normal-hearing group are presented in Table 4.8.

In the SNHL group, most correlations among VEMP parameters were also not statistically significant ($p > 0.05$). This was seen across most of the latency, rectified amplitude, and asymmetry ratio measures. A significant negative correlation was found between p13 latency and the mVEMP asymmetry ratio. A negative correlation was also found between mVEMP latencies and cVEMP rectified amplitude in the hearing-impaired group. The detailed correlation results for the SNHL group are presented in Table 4.8.

Table 4.8

Bivariate correlation coefficients ® among cVEMP, oVEMP, and mVEMP parameters in normal-hearing and SNHL groups.

	Statistics	p11 Latency	n21 Latency	mVEMP Rectified Amplitude	mVEMP Asymmetry Ratio	n10 Latency	p15 Latency	oVEMP Rectified Amplitude	oVEMP Asymmetry Ratio
Normal Hearing									
p13 Latency	*R*	-0.070	-0.323	-0.015	0.416	0.232	0.143	0.149	0.111
	P	0.775	0.178	0.951	0.077	0.353	0.570	0.556	0.660
n23 Latency	*R*	-0.415	-0.308	0.310	0.010	-0.155	0.003	0.210	-0.350
	P	0.077	0.199	0.196	0.968	0.539	0.992	0.402	0.154
cVEMP Rectified Amplitude	*R*	-0.113	-0.366	-0.202	0.187	0.234	0.041	0.317	0.540
	P	0.644	0.124	0.406	0.443	0.350	0.873	0.200	0.021
cVEMP Asymmetry Ratio	*R*	-0.150	-0.065	0.422	-0.086	-0.334	-0.219	-0.119	0.041
	P	0.541	0.791	0.072	0.727	0.175	0.383	0.639	0.872
n10	*R*	0.184	-0.128	-0.143	-0.266				
	P	0.466	0.612	0.573	0.287				
p15	*R*	0.096	-0.110	0.234	-0.547				
	P	0.705	0.663	0.351	0.019				

oVEMP Rectified Amplitude	*R*	0.391	0.201	-0.180	0.231				
	P	0.108	0.424	0.476	0.355				
oVEMP Assymetry Ratio	*R*	0.090	-0.050	-0.205	0.212				
	P	0.723	0.845	0.415	0.397				
SNHL									
p13Latency	*R*	-0.138	-0.237	0.011	-0.796	-0.253	-0.409	0.411	-0.058
	P	0.685	0.483	0.975	0.003	0.383	0.146	0.145	0.844
n23 Latency	*R*	0.347	0.325	0.199	-0.576	-0.463	-0.290	0.384	0.091
	P	0.296	0.330	0.558	0.064	0.095	0.314	0.176	0.757
cVEMP Rectified Amplitude	*R*	-0.648	-0.638	-0.391	-0.256	0.011	-0.174	0.179	0.402
	P	0.043	0.047	0.263	0.475	0.973	0.570	0.558	0.173
cVEMP Asymmetry Ratio	*R*	0.569	0.478	0.499	0.288	0.272	-0.064	-0.215	-0.267
	P	0.086	0.162	0.142	0.420	0.368	0.834	0.480	0.378
n10 Latency	*R*	-0.103	-0.422	0.032	0.113				
	P	0.791	0.258	0.934	0.772				
p15 Latency	*R*	-0.444	-0.605	-0.289	0.118				
	P	0.231	0.084	0.450	0.762				

oVEMP Rectified Amplitude	*R*	-0.164	-0.080	-0.256	-0.355
	P	0.674	0.837	0.505	0.348
oVEMP Assymetry Ratio	*R*	0.089	-0.049	0.275	-0.410
	P	0.819	0.900	0.474	0.273

Note. The values presented in the table represent p-values obtained from bivariate correlation analysis. $p < 0.05$ indicates statistically significant correlation. p13 and n23 are latency of cVEMP, n10 and p15 represent the latency of oVEMP, and p11 and n21 represent latency of mVEMP.

Overall, the present study examined the response rate, latency, amplitude, asymmetry ratio, and relationship among cVEMP, oVEMP, and mVEMP parameters in the normal-hearing and SNHL groups. The results showed that the response rate for mVEMP was significantly lower in the SNHL group than in the normal group, whereas there was no significant difference for response rate for cVEMP and oVEMP between the normal and SNHL groups. Similarly, Latency did not show any significant difference across all the VEMPs, cVEMP, oVEMP and mVEMP between the normal and SNHL group. However, the amplitude of mVEMP and cVEMP was found to be significantly lower in the SNHL group than in normals, but no significant difference was found in oVEMP amplitude between the groups. A significant negative correlation was observed between p15 latency and the mVEMP asymmetry ratio in the normal-hearing group. In the SNHL group, a significant negative correlation was found between p13 latency and the mVEMP asymmetry ratio. A negative correlation was also found between mVEMP latencies and cVEMP rectified amplitude in the hearing-impaired group. No other significant correlations were observed among the remaining parameters.

Chapter 5

Discussion

The present study aimed to compare cVEMP, oVEMP, and mVEMP findings between individuals with bilateral moderate-to-profound sensorineural hearing loss and normal-hearing individuals. Response rate, latency, amplitude, and asymmetry ratio were analysed across all three VEMP tests. Correlation analysis was also carried out to examine the relationship among the three vestibular pathways. The results have already been presented in the previous section; the following sections discuss these findings in detail, drawing on existing literature and possible physiological explanations

5.1 Response rate

The response rate findings showed that adults with bilateral moderate-to-profound sensorineural hearing loss had reduced response rates in all three VEMPs compared to the normal hearing group, and the reduction was found to be greatest and statistically significant in the mVEMP. mVEMP was present in 38ears in the normal-hearing group, whereas it was present in only 22 ears in the SNHL group. These findings suggest that cochlear pathology in the SNHL group may be affecting the vestibular pathways, which may not be clinically visible. Relatively preserved cVEMP and oVEMP response rates suggest that the sacculo-collic and utriculo-ocular pathways may be comparatively less affected than the vestibulo-trigeminal pathway in individuals with SNHL.

The observed findings are physiologically possible because the cochlea and vestibular organs share a common embryological origin and are located in close anatomical proximity. Therefore, pathology affecting the cochlea may also extend to adjacent vestibular structures, particularly the otolith organs.

Previous studies have also reported reduced or abnormal VEMP responses in the SNHL group, supporting the presence of vestibular involvement in the SNHL group. A study done by Ciodaro et al. (2020) reported reduced cVEMP response in individuals with moderate to profound SNHL. Similarly, Xu et al. (2015) evaluated the otolith function in people with profound sensorineural hearing loss, and found abnormal cVEMP and oVEMP responses in both children and adults. Beshr et al. (2020) compared the cVEMP and oVEMP in unilateral sensorineural hearing loss and reported abnormalities in both VEMPs (cVEMP & oVEMP) in the SNHL group, further supporting the coexistence of cochlear and vestibular dysfunction. However, some studies have reported preserved VEMP responses in individuals with sensorineural hearing loss. Bansal et al. (2013) reported the presence of cVEMP responses in 100% and oVEMP responses in 66% of individuals with severe-to-profound sensorineural hearing loss, suggesting that vestibular involvement may not occur uniformly across all vestibular pathways.

Since mVEMP was found to be the most affected among the three VEMPs, it may indicate greater involvement of the vestibulo-trigeminal pathway in the SNHL group. As mVEMP evaluates the vestibulo-trigeminal reflex pathway involving the vestibular nuclei and trigeminal motor pathway, it is anatomically more complex than the other VEMP pathways and may therefore be affected even when the other pathways remain relatively preserved.

Studies investigating mVEMP findings in individuals with sensorineural hearing loss are limited. Deriu et al. (2007) in one of the earliest studies on mVEMP in profound SNHL, reported present mVEMP responses in five individuals with hearing loss, including four with congenital SNHL and one with acquired SNHL. In contrast, the present study showed a marked reduction in mVEMP response rate in individuals with bilateral moderate-to-profound SNHL. Similarly, Sarkar and Sinha (2023) also reported reduced mVEMP response rates in individuals with severe-to-

profound SNHL, with responses present in only 9 out of 20 ears. The reduced or absent mVEMP responses observed in the present study may suggest associated vestibular involvement along with cochlear pathology in individuals with SNHL.

Overall, the reduced mVEMP response rate observed in the present study supports the presence of vestibular involvement in individuals with bilateral moderate-to-profound sensorineural hearing loss, even in the absence of obvious vestibular symptoms. These findings highlight the importance of vestibular assessment in individuals with SNHL. Including mVEMP along with conventional VEMP testing may provide additional information regarding otolith involvement that could be missed by conventional VEMPs alone, particularly in cases where vestibular dysfunction is hidden.

5.2 VEMP parameters

5.2.1 Latency Findings

The study did not reveal any statistically significant difference in the latency parameters of cVEMP, oVEMP, and mVEMP between the normal-hearing and SNHL groups. These findings suggest that the neural conduction timing across the sacculo-collic, utriculo-ocular, and vestibulo-trigeminal pathways remained relatively preserved despite the presence of bilateral moderate-to-profound sensorineural hearing loss. Although slightly prolonged mVEMP latencies (p11) were observed in the SNHL group, the difference was not statistically significant.

Physiologically, relatively unchanged VEMP latencies may suggest that neural transmission along the vestibular pathways remains fairly intact in individuals with SNHL. However, normal latency findings do not necessarily mean that the vestibular system is functioning normally. Instead, they may indicate that the remaining functional neural fibres are still able to conduct neural impulses effectively, even when the overall response strength is reduced. This

interpretation is supported by the present mVEMP findings, where reduced response rates were observed despite relatively preserved latency measures.

These findings are consistent with several previous studies in individuals with SNHL. El Kousht et al. (2021) evaluated cVEMP and oVEMP in individuals with sensorineural hearing loss and reported no statistically significant difference in P1 and N1 latencies of cVEMP and oVEMP between the SNHL group and the control group, which is in direct agreement with the present findings. Selim et al. (2012) reported no significant difference in cVEMP latencies in children with sensorineural hearing loss compared to controls. Similarly, Zhang et al. (2024) reported reduced cVEMP and oVEMP response rates with preserved latencies in individuals with sudden sensorineural hearing loss. Wang et al. (2019) also reported relatively preserved VEMP latencies in individuals with sudden sensorineural hearing loss without vertigo. Collectively, these findings suggest that latency measures may remain relatively stable in cochleo-vestibular disorders, particularly when the pathology is partial or incomplete.

However, not all findings are in agreement. El Kousht et al. (2021) reported a statistically significant positive correlation between cVEMP and oVEMP latencies and the degree of hearing loss in the SNHL group, suggesting that while latencies may remain within normal limits, they tend to shift as cochlear damage progresses. The discrepancy between these studies and the present findings may be due to differences in the degree of hearing loss, age of the participants, and the cause of SNHL.

With respect to mVEMP findings, the present study showed slightly prolonged latencies in the SNHL group, although the difference was not statistically significant. A similar trend was reported by Sarkar and Sinha (2023), who observed significantly prolonged mVEMP latencies in individuals with severe-to-profound sensorineural hearing loss. They suggested that prolonged

VEMP latencies may indicate possible retro-labyrinthine involvement, as previously discussed by Bansal et al. (2013). In addition, Deriu et al. (2007) proposed that different components of mVEMP may have contributions from both vestibular and auditory systems. Therefore, the slight prolongation in mVEMP latencies observed in the present study may reflect the influence of auditory dysfunction along with vestibular involvement in individuals with SNHL. However, further studies are required to better understand the physiological origin of different mVEMP components.

Overall, the available evidence points towards latency measures being largely preserved in individuals with sensorineural hearing loss, and where changes are seen, they appear to be more related to how severe the hearing loss is.

5.2.2 Amplitude Findings

The findings showed reduced rectified amplitudes across cVEMP, oVEMP, and mVEMP responses in individuals with bilateral moderate-to-profound SNHL, with the greatest reduction observed in mVEMP. Significant reduction was observed only for cVEMP and mVEMP rectified amplitudes, whereas oVEMP amplitude did not show a statistically significant difference.

Physiologically, VEMP amplitude is influenced by the integrity of the otolith organs, the number of functioning neural fibres, neural synchrony, and the effectiveness of the vestibular reflex pathways. When hair cells or vestibular nerve fibres are partially affected, fewer neurons may respond to acoustic stimulation, resulting in reduced amplitudes even when neural conduction timing remains relatively preserved.

The findings of the study are in accordance with the previous VEMP studies in the SNHL population. Selim et al. (2012) observed significantly reduced cVEMP amplitudes in children with sensorineural hearing loss despite relatively preserved latency measures. Similarly, Bansal et al.

(2013) also reported reduced cVEMP and oVEMP amplitudes in individuals with severe-to-profound hearing loss, indicating possible vestibular involvement along with cochlear pathology. Likewise, Wang et al. (2019) reported reduced oVEMP amplitudes with relatively preserved latencies in individuals with sudden sensorineural hearing loss. Together, these findings suggest that amplitude measures may be affected earlier and may be more sensitive than latency measures in identifying cochleo-vestibular involvement.

Although oVEMP amplitudes were reduced in the SNHL group, the difference was not statistically significant. This may suggest that the utriculo-ocular pathway is comparatively less affected than the other vestibular pathways in individuals with SNHL. Variations in the severity, aetiology, progression of hearing loss, and extent of vestibular involvement may contribute to the relatively lesser reduction in oVEMP amplitude. Similar findings were reported by El Kousht et al. (2021), where oVEMP amplitudes in individuals with SNHL were lower than those of the control group, although the reduction was not statistically significant. The absence of statistical significance does not necessarily indicate normal vestibular functioning, as clinically reduced amplitudes were still observed in the SNHL group.

Among the three VEMPs, mVEMP showed the greatest reduction in rectified amplitude in the SNHL group. Since mVEMP evaluates the vestibulo-trigeminal reflex pathway, the findings may suggest greater involvement of this pathway in individuals with sensorineural hearing loss. As this pathway involves additional brainstem connections, it is more anatomically complex than the cVEMP and oVEMP pathways and may therefore be more susceptible to cochleo-vestibular changes. Literature related to mVEMP findings in individuals with SNHL is still limited. Sarkar and Sinha (2023) also reported reduced mVEMP amplitudes along with lower response rates in individuals with severe-to-profound hearing loss, although the reduction in amplitude was not

statistically significant. In contrast, Deriu et al. (2007) did not observe a significant reduction in mVEMP amplitudes in hearing-impaired individuals. They suggested that mVEMP responses may be influenced by both cochlear and vestibular function, indicating possible contributions from auditory as well as vestibular systems. Since only a few studies have explored mVEMP findings in individuals with SNHL, these findings should be interpreted cautiously.

Clinically, rectified amplitude measures may be more sensitive than latency measures in identifying vestibular involvement in individuals with moderate-to-profound sensorineural hearing loss. The findings of the present study also highlight the importance of including mVEMP along with conventional VEMP testing as part of a comprehensive vestibular assessment. This may help in identifying possible subclinical vestibular dysfunction in individuals with SNHL, even when visible vestibular symptoms are absent.

5.2.3 Asymmetry Ratio Findings

Across all three VEMPs, the asymmetry ratio was largely comparable between the SNHL and normal-hearing groups. A statistically significant difference was observed only for the oVEMP asymmetry ratio, while cVEMP and mVEMP asymmetry ratios remained similar between the groups. This pattern suggests that vestibular involvement in individuals with bilateral moderate-to-profound SNHL tends to occur fairly symmetrical across both ears.

The asymmetry ratio captures the interaural difference in vestibular responses and is primarily useful in identifying unilateral dysfunction. Since the present study included participants with symmetrical bilateral hearing loss, any associated vestibular involvement was likely to have affected both ears to a similar degree, naturally keeping the asymmetry ratio within comparable limits. This makes the asymmetry ratio less informative in this population, as it depends on an interaural imbalance that may simply not exist when both ears are affected together.

Previous VEMP studies have reported similar findings, suggesting that the asymmetry ratio tends to remain relatively unaffected in cases of bilateral vestibular involvement. Takeuti et al. (2019) found no statistically significant difference in the cVEMP asymmetry ratio between individuals with profound bilateral SNHL and controls, despite the SNHL group showing an 8.52 times higher likelihood of presenting altered cVEMP results overall. This is an important observation; a normal asymmetry ratio does not rule out vestibular involvement, particularly in bilateral conditions. El Kousht et al. (2021) also reported comparable asymmetry ratios between the SNHL and control groups, further supporting the view that bilateral cochlear pathology tends to affect both vestibular systems to a similar degree, leaving the interaural asymmetry relatively intact. Apart from underlying pathology, asymmetry ratio values can also be affected by differences in muscle contraction levels, electrode placement, and stimulus delivery between ears, which adds further reason not to rely on it as a standalone measure.

The significantly higher oVEMP asymmetry ratio in the SNHL group does point to some degree of utricular imbalance between the ears, meaning the utriculo-ocular pathway was not equally affected on both sides in all participants. However, given that cVEMP and mVEMP asymmetry ratios were largely preserved, the more consistent picture of vestibular involvement in this population came through reduced response rates and rectified amplitudes rather than asymmetry ratio changes. Clinically, this reinforces the importance of evaluating all VEMP parameters together response rate, amplitude, latency, and asymmetry ratio, rather than drawing conclusions from any single measure.

5.3 Correlation Analysis Findings

The correlation analysis in the present study revealed mostly non-significant associations among cVEMP, oVEMP, and mVEMP parameters in individuals with bilateral moderate-to-

profound sensorineural hearing loss. These findings suggest that the three VEMPs do not consistently reflect vestibular involvement as a unified measure, and that each test may be capturing dysfunction across a different vestibular pathway independently.

This is physiologically plausible. Although cVEMP, oVEMP, and mVEMP all originate from vestibular end organs, they travel through different central pathways and are recorded from different target muscle groups. The cVEMP reflects the sacculo-collic reflex, oVEMP the utriculo-ocular reflex, and mVEMP the vestibulo-trigeminal reflex. As mVEMP evaluates the vestibulo-trigeminal reflex pathway, which is anatomically and functionally distinct from the sacculo-collic and utriculo-ocular pathways, it is expected that its parameters may not strongly correlate with cVEMP and oVEMP findings. Given these differences, it is reasonable that one pathway may be affected while others remain relatively intact, and that changes observed in one VEMP may not always correspond to changes in another.

Previous studies have reported similar patterns, where cVEMP and oVEMP findings did not consistently align in individuals with sensorineural hearing loss. Bansal et al. (2013) found no significant association between cVEMP and oVEMP results in individuals with severe-to-profound SNHL, supporting the idea that saccular and utricular pathways can be affected independently. J. Shen et al. (2023) observed that the abnormal rate of oVEMP was significantly higher than that of cVEMP in individuals with sudden SNHL, further indicating that these two pathways can be affected to different degrees within the same individual. Tanyeri et al. (2020) also reported that oVEMP abnormalities were more frequent than cVEMP abnormalities in adults with prelingual hearing loss, suggesting that utricular dysfunction may be more common than saccular dysfunction in individuals with SNHL. In contrast, Beshr et al. (2020) observed some degree of association between cVEMP and oVEMP findings in individuals with unilateral SNHL, which

reflected greater vestibular asymmetry associated with unilateral rather than bilateral involvement. It is worth noting that the available literature predominantly addresses the relationship between cVEMP and oVEMP findings, and studies specifically examining correlations among all three VEMPs, including mVEMP, are virtually absent. This is likely because mVEMP is a relatively newer test and its relationship with cVEMP and oVEMP in cochleo-vestibular disorders has not been systematically explored yet. The present findings, therefore, represent a novel contribution and highlight the need for further research in this area.

A few significant correlations were noted in the present study, though these should be interpreted with caution. The negative correlation between cVEMP amplitude and mVEMP latency, and the positive correlation between p13 latency and mVEMP asymmetry ratio, may reflect a minor degree of overlap between adjacent neural pathways, or may simply be attributable to natural physiological and recording variability rather than a shared underlying pathological process.

Clinically, these findings support the use of all three VEMPs together in the vestibular assessment of individuals with SNHL. Since each test evaluates a distinct reflex pathway, relying on one or two tests alone may result in missing vestibular dysfunction that is only apparent in a specific pathway. A comprehensive approach incorporating cVEMP, oVEMP, and mVEMP may therefore provide a more complete picture of vestibular involvement in this population.

Chapter-6

Summary and conclusion

The cochlea and vestibular end organs are closely related structures — they share a common embryological origin, anatomical proximity, and blood supply, which means that pathology affecting one may not always remain confined to the other. It is therefore not surprising that vestibular dysfunction is a recognised comorbidity in individuals with sensorineural hearing loss (SNHL), even when balance-related symptoms are absent. Vestibular evoked myogenic potentials (VEMPs) are objective electrophysiological tests that allow clinicians to assess otolith organ function and vestibular reflex pathway integrity non-invasively. Cervical VEMP (cVEMP) evaluates the saccule and inferior vestibular nerve via the sacculo-collic pathway, ocular VEMP (oVEMP) assesses the utricle and superior vestibular nerve via the utriculo-ocular pathway, and masseter VEMP (mVEMP) reflects the integrity of the saccule and the vestibulo-trigeminal brainstem reflex pathway (Nagarajan & Sinha, 2024). While cVEMP and oVEMP findings in SNHL have been studied to a reasonable extent, the contribution of mVEMP in this population remains insufficiently explored. The present study therefore aimed to compare all three VEMP modalities in adults with bilateral moderate-to-profound SNHL and to examine the correlations among these three vestibular reflex pathways.

To achieve our aim of establishing relationships among cVEMP, oVEMP, and mVEMP in individuals with moderate to profound SNHL, the study comprised two groups. Group 1 consisted of 20 individuals diagnosed with moderate-to-profound sensorineural hearing loss , while Group 2 included 20 individuals with normal hearing sensitivity. After a detailed audiological evaluation, all participants underwent cervical, ocular, and masseter VEMP recordings using 500Hz tone-burst

stimuli presented in air-conduction mode. The waveforms were recorded and analysed for response rate, latency, rectified amplitude and asymmetry ratio.

1. Statistical analysis revealed that the mVEMP response rate was significantly lower in the SNHL group than in the normal-hearing group.
2. Latency analysis revealed no statistically significant difference between the normal and SNHL groups.
3. Among the three VEMPs, cVEMP and mVEMP's rectified amplitude was found to be significantly lower in the SNHL group than in normals, and the reduction was greater in mVEMP amplitude than in cVEMP.
4. The asymmetry ratio value showed a relatively small difference between the normal and SNHL group. Most asymmetry ratio measures did not show statistically significant differences, except for the oVEMP asymmetry ratio between normals and SNHL.
5. Only a few significant correlations were observed between certain cVEMP, oVEMP, and mVEMP parameters. The findings suggest that the three VEMP modalities may represent relatively independent vestibular reflex pathways.

Overall, mVEMP was most affected in individuals with bilateral moderate-to-profound sensorineural hearing loss among the three in the SNHL group, particularly the response rate and rectified amplitude. This may suggest greater involvement of the vestibulo-trigeminal pathway in individuals with hearing loss.

Conclusions

The cochlea and vestibular structures share more than just anatomical space — damage to one often has consequences for the other, even when those consequences are not immediately visible. The present study examined this relationship by comparing cVEMP, oVEMP, and mVEMP

in adults with bilateral moderate-to-profound sensorineural hearing loss, with particular interest in whether the vestibulo-trigeminal pathway assessed by mVEMP shows meaningful involvement in this population.

The findings indicate that vestibular involvement in individuals with SNHL is real, measurable, and broader than conventional testing may suggest. Among the three modalities, mVEMP was the most affected, showing significantly reduced response rates and amplitudes in the hearing-impaired group. cVEMP amplitudes were also significantly reduced, while oVEMP showed a significant increase in asymmetry ratio, pointing to some degree of utricular imbalance between the two ears. Importantly, latencies were preserved across all three modalities, suggesting that while the strength of vestibular responses is reduced, the timing of neural conduction along these pathways remains largely intact.

The lack of significant correlations among the three VEMP modalities further suggests that each pathway is affected independently. This means that findings from one VEMP test cannot reliably predict findings from another, and that a comprehensive assessment using all three modalities together provides a more complete picture of vestibular function in this population.

From a clinical standpoint, many individuals with SNHL do not report balance-related symptoms, yet the present findings suggest that subclinical vestibular dysfunction may be more common than is routinely recognised. Including mVEMP as part of the vestibular assessment battery in individuals with SNHL may therefore help identify involvement that would otherwise go undetected.

In conclusion, the vestibulo-trigeminal pathway appears to be disproportionately affected in bilateral moderate-to-profound sensorineural hearing loss. A comprehensive VEMP battery that

includes cVEMP, oVEMP, and mVEMP offers a more thorough evaluation of vestibular function in this population and may improve the clinical detection of hidden vestibular dysfunction.

Chapter 7

Limitations and Future Directions

7.1 Limitations of the Study

The present study was carried out with careful attention to methodological error; however, several limitations must be acknowledged when interpreting the findings. First, the sample comprised 20 adults with bilateral moderate-to-profound sensorineural hearing loss and 20 age- and gender-matched normal-hearing controls. While this was sufficient for an exploratory comparison, the relatively small sample size reduces statistical power, particularly for parameters such as latency and asymmetry ratio, where trends were observed but significance was not reached. The findings must therefore be interpreted with caution before being generalised to the broader SNHL population.

Second, the study was limited to individuals with moderate-to-profound SNHL, and the findings cannot be directly extended to those with mild degrees of hearing loss. Since the extent of cochlear damage is likely to influence the degree of vestibular involvement, the absence of a graded severity range restricts the interpretability of the results. Similarly, the aetiology of hearing loss was not formally considered, and the SNHL group represented a heterogeneous population in terms of underlying cause. Noise-induced, age-related, and idiopathic SNHL may each carry different patterns of vestibulo-cochlear involvement, and this variability was not accounted for in the present design.

Third, the duration of hearing loss was not formally documented or controlled. It is plausible that individuals with a longer history of SNHL may demonstrate greater vestibular pathway compromise due to progressive pathological changes over time. The cross-sectional nature of the study design further limits the ability to make any inferences regarding progression

relationships between cochlear and vestibular deterioration. A longitudinal design would be necessary to address these questions.

Fourth, vestibular function was assessed exclusively through VEMP testing, without the inclusion of complementary measures such as vHIT, rotary chair testing, or computerised dynamic posturography. Although VEMPs provide objective and clinically useful information about otolith organ and brainstem reflex pathway integrity, they do not capture the full range of vestibular function. The extent of vestibular dysfunction in the SNHL group may therefore be only partially characterised by the present assessment. Additionally, no validated questionnaire was used to screen for subclinical vestibular symptoms, which means that functional balance difficulties not spontaneously reported by participants may have been missed.

Fifth, all three VEMP modalities were recorded using a single stimulus type, specifically 500 Hz tone burst stimuli presented at 125 dB peSPL via air conduction. This approach, while standard in clinical practice, does not account for potential frequency-specific differences in vestibular sensitivity or the possible influence of audiometric configuration on stimulus transmission.

Finally, The relatively limited published research on mVEMP in SNHL populations made it challenging to contextualise the present findings within an established evidence base. Therefore, the mVEMP findings should be considered preliminary until confirmed by future studies.

7.2 Future Directions

The findings of the present study highlight several areas requiring further investigation. Future studies should include larger sample sizes spanning all degrees of sensorineural hearing loss, from mild to profound, to determine whether a systematic relationship exists between hearing loss severity and vestibular pathway involvement. Classifying participants by cause and duration

of hearing loss would further help clarify how different underlying conditions contribute to cochleo-vestibular dysfunction.

Longitudinal studies tracking VEMP parameters over time would help establish whether vestibular pathway involvement is progressive and at what stage it becomes detectable. Future research should also combine cVEMP, oVEMP, and mVEMP with vHIT and posturography to provide a more complete picture of vestibular function in individuals with SNHL, and to identify the most effective combination of tests for detecting early dysfunction.

Since mVEMP showed the greatest involvement among the three VEMP modalities in the present study, its potential role as a monitoring tool before and after cochlear implantation warrants further attention. Future research could determine whether mVEMP provides additional diagnostic or prognostic value beyond conventional VEMPs. Exploring alternative stimulus parameters, such as bone-conducted and CE-Chirp stimuli across multiple frequencies, may also improve mVEMP response rates in hearing-impaired individuals and enhance its clinical usefulness. Finally, establishing normative mVEMP data specific to Indian adults across a wider age range would improve the reliability of clinical interpretation in this population.

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INSTITUTE REVIEW BOARD (IRB) APPROVAL FOR BIO-BEHAVIOURAL RESEARCH PROPOSAL INVOLVING HUMAN SUBJECTS AT AIISH

AIISH Institute Review Board (IRB)

Ref: SH/IRB/M.4/AUD.04/2025-26 **Date: 06.01.2026**

Title of the Dissertation	: Cervical, Ocular, and Masseter VEMPs in Individuals with Bilateral Moderate to Profound Sensorineural Hearing Loss
Name of the Investigator	: Bhumika
Guide	: Ms. Nirupama S
Co-Guide (if any)	: Dr. Sujeet Kumar Sinha
Proposed Duration of the Project	: 08 months
Source of funding	: Non-funded Master's dissertation
Estimated budget	: Nil
Reference Number of the Project	: Nil
Date on which the IRB meeting was held	: 02.01.2026
A clear statement of the decision reached IRB meeting (In the vent of the proposal is not approved, a statement of reasons for the same must be indicated)	: **APPROVED**
Advice & suggestions (if any)	: NIL

Signature & Name of the Member Secretary-IRB
Dr. Animesh Barman
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सदस्य सचिव / Member Secretary
संस्थागत समीक्षा बोर्ड
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