Objective assessment of otolith and SCCs functions in individuals with severe to profound hearing loss

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This Dissertation is submitted as part fulfillment
For the Degree of Master of Science in Audiology
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ALL INDIA INSTITUTE OF SPEECH AND HEARING
MANSAGANTOTHRI, MYSURU-570006
MAY, 2016

CERTIFICATE

This is to certify that this dissertation entitled "**Objective assessment of otoltith and SCCs functions in individuals with severe to profound hearing loss**" bonafide work submitted in part fulfillment for the degree of Master of science (Audiology) of the student (Registration No: 14AUD022). 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 or any other diploma or degree.

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CERTIFICATE

This is to certify that this dissertation entitled "**Objective assessment of otoltith and SCCs functions in individuals with severe to profound hearing loss**" has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other university for the award or any other Diploma or Degree.

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DECLARATION

I hereby declare that this dissertation entitled "**Objective assessment of otoltith and SCCs functions in individuals with severe to profound hearing loss**" is the result of my own study under the guidance of **Dr.Sujeet Kumar Sinha** Reader Audiology, Department ofAudiology, All India Institute of Speech and Hearing, Manasagangothri, Mysuru and has not been submitted earlier to any other university for the award or any other Diploma or Degree.

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Hamesha apni alag pehchan bnao,
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With love to Papa

-Your words have always been an inspiration to me.☺

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Abstract

Aim: This study was designed to objectively assess the functioning of otolith (saccule and utricle) and three semicircular canals in individual with severe to profound sensorineural hearing loss using cVEMP, oVEMP and vHIT respectively.

Method: Twenty adult participants (40 ears) having severe to profound hearing loss ranging in age from 15-40 years in group I. Group-II consisted of 20 adult participants (40 ears) in the age range from 15-40 years with normal hearing sensitivity. All the participants underwent a detailed case history, pure tone audiometry, immitance and reflexometry, cVEMP, oVEMP and vHIT tests.

Results: cVEMP was present in 90% and 75% in right and left ear of individual with severe to profound hearing loss respectively. No significant difference between the latencies of both the groups whereas significant difference was found between the p1-n1 amplitude complexes of both the group in which smaller amplitude was found for individual with severe to profound hearing loss. oVEMP was present in 55% and 60% in right and left ear of individual with severe to profound hearing loss respectively. No significant difference between the latencies of n1, p1 and n2 of both the groups whereas significant difference was found for the amplitude complex of p1-n1 and p1-n2 of both the groups. Mean VOR gain values for right and left horizontal canals, right anterior and left posterior canal for individual with hearing impaired is lesser than the individual with normal hearing. There were significant differences between group 1 and group 2 for VOR gain for right horizontal canal and left horizontal canal whereas significant difference was showed in right posterior canal, left anterior canal, right anterior canal and left posterior canal. No association found between cVEMP, oVEMP and different planes of vHIT of right ear.

Conclusions: To conclude, vestibular abnormality was seen for both otolith organs (saccule and utricle) and semi circular canals in individual with severe to profound hearing loss. Therefore, vestibular tests should be included along with various audiological tests in the diagnostic protocol for the assessment of individual with severe to profound sensorineural hearing loss.

Chapter-1

INTRODUCTION

The vestibular system is broadly categorized into both peripheral and central system. The peripheral system is bilaterally composed of three semicircular canals (posterior, superior, lateral) and the otolithic organs (saccule and utricle). The semicircular canals detect rotational head movement while the utricle and saccule respond to linear acceleration and gravity, respectively. These vestibular organs are in a state of symmetrically tonic activity, that when excited stimulate the central vestibular system. This information, along with proprioceptive and ocular input, is processed by the central vestibular pathways (e.g. vestibular nuclei) and maintains our sense of balance and position.

Also, vestibular system is responsible for stabilizing the position of the eyes, head and body in space, and helps to maintain an upright stance. It is composed of two parts, each with different roles: (1) the vestibular—ocular system, responsible for visual stabilization; and (2) the vestibular—spinal system, which maintains the orientation of the body in space and contributes to the postural tone necessary for the acquisition of motor developmental milestones.

Vestibular Evoked Myogenic Potential (VEMP) is a non-invasive test to assess the functioning of otolith organs of inner ear. It is a short latency muscle potential which is elicited by the presentation of loud sound. One of the variant of VEMP is Cervical VEMP (cVEMP) which has been found to be originated from the saccule (Colebatch, Halmagyi, & Skuse, 1994; Todd, Cody, & Banks, 2000). It has been found to be useful in finding out the pathology of the saccule or its end organ pathologies in various vestibular disorders such as: vestibular neuritis (Chihara et al., 2012 ; Manzari, Burgess, & Curthoys, 2012) cerebellopontine angle tumor (Beyea &

Zeitouni, 2010; Murofushi & Takehisa, 2001), auditory neuropathy (Sinha, Barman, Singh, Rajeshwari & Sharanya, 2013). Also, the cVEMPs has been found useful in the diagnosis of other vestibular pathologies such as Semicircular canal dehiscence syndrome (Brantberg & Verrecchia, 2012) and multiple sclerosis (Murofushi, Shimizu, Takegoshi, & Cheng, 2001).

Another variant of Vestibular Evoked Myogenic Potential is ocular VEMP (oVEMP), which has been introduced recently and has been suggested to be utricular in origin (Halmagyi Curthoys, Colebatch, 2005; Curthoys, 2010; Welgampola & Carey, 2010; Brandt & Strupp, 2010). It is mediated through vestibulo-ocular reflex pathway. Ocular vestibular evoked myogenic potentials (oVEMPs) also has been utilised in diagnosing inter nuclear ophthalmoplegia (Rosengren & Colebatch, 2011), to differentiate between cerebellar and brainstem lesions (Su&Young.,2011) auditory neuropathy/audiovestibular neuropathy, superior semicircular canal dehiscence syndrome (Rosengren, Aw, Halmagyi, Todd, & Colebatch, 2008) and vestibular neuritis (Murofushi, Nakahara, Yoshimura, & Tsuda, 2011).

Another test which has been utilized recently for the diagnosis is video head impulse test (vHIT). vHIT is quick to administer and noninvasive test. It objectively measures the head velocity and the eye velocity response during brief, abrupt, unpredictable, passive head rotations, and so provides a measure of vestibulo-ocular reflex (VOR) gain and VOR gain asymmetry. It provides an absolute measure of the functional level of every semicircular canal separately. It allows the clinician to diagnose patients with VN acutely while they are ill and assess them again after they have recovered, providing objective evidence of the VOR deficit and the extent of its recovery.

vHIT helps to improve diagnostic accuracy for patients with acute spontaneous vertigo. vHIT is also able to overcome the problems that is being faced while using rotational chair test. As rotational chair test have used big expensive chairs, with low accelerations which put the patient to sleep. vHIT can be performed in a fully lit room and even during acute attacks of vertigo. vHIT help to detect vertical canal dysfunction (MacDougall et al., 2013) . Also, measure the individual SCC's which help to diagnose pheripheral vestibular loss, such as superior and inferior vestibular neuritis.

Anatomical, histological and physiologic similarities between the cochlear and vestibular end organs explain the relation between hearing loss and vestibular disturbs. As both systems are related, in patients with hearing loss it is important to study the complete balance in order to diagnose and prevent a worse vestibular problem. Since vHIT assesses the SCC's, cVEMP assesses the saccule and oVEMP assesses the utricle, the administration of three tests together will complete the picture of the vestibular system in individuals with severe to profound hearing loss.

Need of the present study:

- 90% of the individual with sensorineural hearing loss is caused by damage to the cochlea or the vestibulocochlear nerve (Agrawal, Platz & Niparko, 2008). The vast majority of those with SNHL have bilateral impairment. Cochlea and the vestibule share the continuous membranous labyrinth of the inner ear through ductus reunions anatomically. So, there are chances that in individuals with sensorineural hearing loss, disturbances of cochlear function could accompany with vestibular impairment. Various studies have reported the prevalence of VEMP abnormality from 53% (Jafari & Asad Malayeri, 2011) to 67% in severe to profound hearing loss individuals (Bansal, Sahani &

Sinha, 2013). Affected VEMP is suggestive of affected utricular function being more linked to the cochlea than saccular function in individuals with severe to profound hearing loss. There is dearth of information regarding the function of semicircular canal in individual with severe to profound hearing loss. Also, there is a study reported in the literature regarding the difficulty in balancing among the individuals with sensorineural hearing loss (Schuknecht, 1993; Voelker & Chole, 2010). Therefore diagnostic evaluation of the vestibular system becomes an essential aspect.

- There are numerous reports of vestibular and balance dysfunction in hearing-impaired children in the literature. Most of this study fails to control for type, degree and etiology of the hearing loss, as well as for other confounding variables. The presence and severity of the peripheral vestibular dysfunction seems to be associated with the etiology and severity of the sensorineural hearing loss; thus, vestibular dysfunction may be more prevalent among profound than the lesser degrees of hearing loss. Hence, the accurate diagnosis of vestibular dysfunction in individuals with sensorineural hearing loss can be a challenging task. This suggests the importance of battery of the objective test to assess the vestibular system in such individuals.
- In each vestibular labyrinth there are 5 vestibular sensory regions. Any one of these can become dysfunctional and can or cannot cause characteristic patient symptoms. Up to now the techniques for assessing the specific function of every sensory region have not been available. However with recent developments it is now possible to test every semicircular canal in both labyrinths by using the video head impulse test (vHIT), and to test every otolithic sense organ by using vestibular evoked myogenic potentials

(VEMPs). The ocular vestibular-evoked myogenic potential (oVEMP) tests dynamic utricular function and the cervical vestibular-evoked myogenic potential (cVEMP) tests dynamic saccular function.

Aims of the study:

The aim of the present study was to objectively assess the functioning of otoliths (saccule and utricle) and three semicircular canal in individual with severe to profound sensorineural hearing loss using cVEMP, oVEMP and vHIT respectively.

Objectives of the Study

- To find out the functioning of utricle, saccule and semicircular canal in individual with severe to profound sensorineural hearing loss using cervical VEMP, ocular VEMP and vHIT respectively.
- To find out an association between cervical VEMP, ocular VEMP and vHIT test in individual with severe to profound sensorineural hearing loss.

Chapter-2

REVIEW OF LITRATURE

In humans, postural stability is maintained by visual, propeoceptive and vestibular system. In vestibular system, the semi circular canals and the otolith organs (saccule and utricle) are responsible for maintaining the postural stability. Semi-circular canals help in balancing during angular acceleration and otolith organs help in balancing during linear acceleration. As the vestibular system consists of multiple structures, a particular test cannot assess the functioning of all the structures. However with recent developments is now possible to test every semicircular canal in both labyrinths by using the video head impulse test (vHIT), and to test every otolith sense organ by using vestibular evoked myogenic potentials (VEMPs). The ocular vestibular-evoked myogenic potential (oVEMP) tests dynamic utricular function and the cervical vestibular-evoked myogenic potential (cVEMP) tests dynamic saccular function.

Clinical applications of vestibular evoked myogenic potential of peripheral vestibular disorders:

1. **Meniere's disease:**

Meniere's disease is characterized by aural fullness, fluctuating hearing loss, recurrent attack of vertigo and tinnitus (Hamann & Arnold, 1999). It has been stated that cVEMP, oVEMP and caloric test provides information about localization of hydrops in individual of Meniere's disease. Sinha, Shankar, Govindaswamy (2015) characterized individual with Meniere's disease (MD's) using cVEMP, oVEMP and caloric test. 25 unilateral MD's and 4 bilateral MD's (total 33ears) participated in

the study and found out of 33 ears with Meniere's disease, 29 ears had absent responses on cVEMP, 23 ears showed absent oVEMP responses, 27 ears had hypo-activity, five ears showed hyper activity and one ear showed normal response to caloric stimulation.

cVEMP and oVEMP can provide useful information about the hydrops localization in the contralateral ears of individuals with Meniere's disease. Sinha et al. (2015) recorded cVEMP and oVEMP in the contralateral ear (25 ears with non-Meniere's disease). Both cVEMP and oVEMP were absent in 5 of the ears, cVEMP was absent and oVEMP was present in 13 ears, cVEMP was present and oVEMP was absent in 1 ear, whereas both cVEMP and oVEMP were present in 6 ears in individuals with Meniere's disease. Authors concluded that the combination of cVEMP and oVEMP provides valuable information regarding localization of hydrops in individuals with Meniere's disease.

Zhu et al. (2014) reviewed the cVEMP responses in 118 participants with Meniere's disease. The authors reported that 95 ears had absence of cVEMP responses in individuals with Meniere's disease. Authors also reported no differences between groups in gender, affected side of the ear, age or duration of symptoms. Further analysis of the data showed that, among 118 ears, three ears had more cVEMP amplitude at 250 Hz, 13 ears had more amplitude at 750 Hz and 56 ears had more cVEMP amplitude at 1000 Hz. The authors concluded that there is either an upward or downward shift in amplitude of cVEMP in individuals with Meniere's disease.

Taylor et al. (2012) recorded cVEMPs at octave frequencies of 250 Hz to 2000 Hz in 20 controls and 20 participants each with clinically definite Meniere's disease. Results were compared with a group of 60 Meniere's disease individuals from a previous study. Inter-aural amplitude asymmetry ratios and amplitude

frequency ratios were compared between groups. The results of the study showed that the amplitude of tone bursts at a frequency of 0.5 KHz to that generated by 1 KHz was significantly lower for individuals with Meniere's disease compared to the normal hearing individuals.

Jerin et al. (2014) evaluated 39 individuals with certain Meniere's disease and recorded oVEMP using 500Hz and 1000Hz air- conducted bursts and found that the for Meniere's ears, the 500/1000 Hz amplitude ratio (mean ratio = 1.20) was significantly smaller when compared to unaffected ears of Meniere's participants (mean ratio = 1.80) or healthy controls (mean ratio = 1.81). Authors concluded that the calculation of the oVEMP 500/1000 Hz amplitude ratio may be a valuable diagnostic tool for Meniere's disease.

Egami et al. (2013) recorded VEMP and caloric test in 114 individuals with Meniere's disease and found that VEMP was present in 50 % of individuals with Meniere's disease whereas present in 51.2% in individuals with Meniere's disease. Different hearing threshold with individuals with Meniere's disease was taken and found that no significant difference in VEMP with different hearing level. However, significant difference was found between hearing level and caloric test. Authors concluded that the combine use of VEMP and caloric test increased the sensitivity to 65.8% for detection of vestibular impairment in individuals with Meniere's disease.

Previous studies reported that the cVEMP and oVEMP tests helps to examine the otoloith organs and their input pathway in individual with peripheal vestibular diorder. Zhang et al. (2015) recorded oVEMP and cVEMP in individual with vestibular diseases. 13 individuals (14 ears) were taken for study in which 3ears with Meniere's disease and air –conducted cVEMP and oVEMP has been recorded using

500Hz tone burst in both the ears and found that oVEMP was present in only 2 ears (14.3%) and cVEMP were abnormal in 11 ears (78.6%).

Rauch et al. (2004) recoded VEMP in 20 adults with unilateral Meniere's disease using click and short tone burst stimuli at 250, 500 and 1,000Hz and found that control group had best repnse at 500Hz whereas Meniere's disease has best response (frequency tuning) at 1000Hz tone burst stimuli. Also, Node et al.(2005) recorded VEMP by using tone bursts at 250, 500, 700, 1000, 1500 , 2000, ad 5000 Hz stimuli in both 28 individulas with Meniere's disease and 36 ears with control group and found that peak amplituse was at 500 Hz tone burst stimuli in control group whereas in Meniere's disease amplitude of cVEMP was more at 1000 Hz.

Frequency amplitude ratio of VEMP is another parameter that has been suited to diagnose Meniere's disease. Singh and Barman (2016) calculated frequency-amplitude ratio (FAR) of oVEMP in identifying Meniere's disease. oVEMP was recorded by using tone bursts of 500, 750, 1000 and 1500Hz and revealed significantly higher FAR in the individual with Meniere's disease for all the frequency. Sensitivity and specificity of 90% and 100% was found for 1000/500 and 750/500 frequency pairs. 100% specificity was found for other frequency pairs whereas 56% of sensitivity was found for individuals with Meniere's disease. Authors concluded that the use of frequency-amplitude ratio with 100/500 frequency pair has high specificity and sensitivity for the diagnosis of individuals with Meniere's disease.

Singh et al. (2015) used frequency amplitude ratio of cVEMP for the diagnosis of Meniere's disease. 22 individual with unilateral definite Meniere's disease were

compared with normal healthy individual. Authors found that frequency amplitude ratio of 750/500, 1000/500, 1500/500 and found tuned frequency/500 for the diagnosis of individuals with Meniere's disease. The frequency amplitude ratio of 750/500 frequency pair produced highest sensitivity (95.45%) and specificity (79.55%) when using a criterion point of ≥1.12 for diagnosis of Meniere's disease. Authors concluded that FAR is a reliable tool for diagnosis of Meniere's disease. The FAR of 750/500 is better suited to the identification of Meniere's disease than 1000/500.

2. Vestibular neuritis:

Vestibular Neuritis is characterized by prolonged severe vertigo with an acute onset. It is not accompanied by any cochlear symptoms or any other neurological symptoms as reported by (Murofushi, Halmagyi, Yavor, & Colebatch, 1996).

Absence of cervical vestibular evoked potentials (cVEMPs) in individual with Vestibular neuritis has been reported due to the involvement of inferior vestibular nerve of involvement of structure that it innervates rather than posterior semicircular canal, BPPV. Therefore, in individual with Vestibular neuritis, variable incidence of abnormal cervical vestibular evoked potentials (cVEMPs) has been reported.

Murofushi, Halmagyi, Yavor, and Colebatch (1996) recorded cervical vestibular evoked potentials (cVEMPs) in 47 individuals with acute Vestibular neuritis, 10 of whom had developed BPPV and found present in unaffected side in all the individuals whereas it was absent in 16 individuals when affected ears were stimulated. The Cervical vestibular evoked potentials (cVEMPs), however was present in all the subjects who had developed BPPV. The authors suggested that the main reason of absence of cervical vestibular evoked potentials is involvement of the saccule and inferior vestibular nerve.

To localize the site of lesion both cVEMP and 3-dimensional videonystagmography were recorded. Cheng, Young and Wu (2000) recorded cervical vestibular evoked myogenic potentials (cVEMPs) and three-dimensional videonystagmography in eight individuals with Vestibular neuritis in order to localize the site of lesion. Authors reported that 7 (88%) of the individuals with vestibular neuritis had bilateral normal Cervical vestibular evoked potentials (cVEMPs). After 1 year of post treatment all 7 individuals showed normal VEMPs bilaterally and absence of caloric response of 5 of the 7 individuals in the affected side. Therefore, author suggested that vestibular neuritis mainly affects the superior vestibular nerve which innervates horizontal semicircular canal and anterior semicircular canal whereas the function of the posterior semicircular canal and saccule which is innervated by the inferior vestibular nerve is preserved.

VEMP helps to monitor the recovery of vestibular neuritis. Ochi, Ohashi and Watanabe (2003) recorded vestibular-evoked myogenic potential (VEMP) in 8 individuals and monitored with unilateral vestibular neuritis the recovery of these disorders. 2 out of 8 individuals with unilateral vestibular neuritis had abnormal cervical vestibular evoked potentials (cVEMPs) and author suggested it to have inferior vestibular nerve disorder. Also one of these individuals showed recovery of the function of the inferior vestibular nerve as assessed by the VEMP and concluded that time course of recoveries of the inferior and superior vestibular nerve systems were similar in the two individuals.

Murofushi, Iwasaki and Ushio (2006), recorded VEMP and caloric tests in 13 individuals with vestibular neuritis. Absence of VEMP was seen in all 13 individuals in initial examination and 5 of them showed recovery of VEMP responses where 4 of

the five individuals showed recovery of VEMP to normal range whereas caloric responses recovered to the normal range in only one individuals.

VEMP can be used as screening test for individual with vestibular neuritis. Nola et al. (2011) recorded VEMP and caloric test in 20 individuals with vestibular neuritis at different duration of acute attack. Authors found that 11 individuals with superior vestibular neuritis showed normal amplitude and latency on both sides of VEMP recording whereas absence of caloric responses in these individuals with superior vestibular neuritis. Nine individuals diagnosed with inferior vestibular neuritis had seen improvement in VEMP response and normal caloric response in all individuals with vestibular neuritis. Authors concluded that VEMP can be used as screening test for individual with vestibular neuritis.

Manzari, Tedesco, Burgess and Curthoys (2010) recorded n10 components of oVEMP in 133 individual with unilateral superior vestibular neuritis with presence of cVEMPs ipsilaterally in all individuals which indicates normal functioning of inferior vestibular nerve. Authors reported that n10 components of bone conduction stimulation were reduced in all 133 individuals with superior vestibular neuritis in contralateral eye relative to ipsilateral eye so that n10 asymmetry was significantly greater than the 50 healthy subjects. Therefore, authors concluded that the n10 component of the oVEMP to bone conduction stimulation is probably mediated by the superior vestibular nerve and so mainly by the utricular receptors and suggested that the oVEMP is effective to identify individual with vestibular neuritis.

Curthoys, Iwasaki, Chihara, Ushio, McGarvie and Burgess (2011) recorded oVEMP to 500Hz air conduction stimulation and 500Hz bone conduction stimulation in 10 individuals with unilateral superior vestibular neuritis and authors reported that the oVEMP potential for air conduction and bone conduction stimulation was reduced

or absent in all 10 (100%) superior vestibular neuritis individuals with normal function of saccular and inferior vestibular nerve and concluded that oVEMP to air conduction stimulation and bone conduction stimulation is predominantly mediated by utricle and superior vestibular nerve.

Ochi, Ohashi and Watanabe (2003) recorded cVEMP and caloric test in 8 individuals with unilateral vestibular neuritis. Abnormal cVEMP was observed in 2 of the 8 individuals with vestibular neuritis and these two individuals were diagnosed to have inferior vestibular neuritis. One of these individuals recovered as measured by recovery in VEMP. The author concluded that the time course of recovery for inferior vestibular neuritis and superior vestibular neuritis are almost similar in participants with vestibular neuritis.

Faralli et al. (2006) recorded VEMPs and repeating canal functioning test at least 6 months after the first episode of vertigo in individuals with acute vestibulopathy. Authors reported the absence of caloric response in almost all the individuals with acute Vestibulopathy in which 4 individuals had presence of vestibular evoked myogenic potentials with Paroxysmal positional vertigo; nine individuals with Persistent dizziness had absence of VEMPs. Recovery was seen in 3 individuals in canal functioning test whereas otolith response was less constant. Absence of VEMP confirms the otolith dysfunction in the onset of dizziness. Therefore authors concluded that combination of VEMPs and canal tests has better clinical significance to diagnose the disorder of vestibular origin.

Lesmas, Pérez, Morera and Piqueras (2009) recorded caloric test and VEMP in 9 individuals with vestibular neuritis to have retrospective study and found females (66.6 %) were more affected than males. Authors reported the absence of caloric response in all 9 individuals whereas 5 in 9 individuals had abnormal VEMP therefore

4 individuals were diagnosed as superior vestibular neuritis (abnormal caloric test, normal VEMP) and another 5 were diagnosed as complete vestibular neuritis (abnormal caloric test, abnormal VEMP). They have not found any cases of inferior vestibular neuritis (normal caloric test, abnormal VEMP). Therefore, authors concluded that complete and superior vestibular neuritis are more frequent than inferior vestibular neuritis and VEMP make it advance in study of Vestibular neuritis.

VEMP help to classify different type of peripheral vestibular disorder. Walther, Schaaf, Sommer and Hörmann (2011) recorded VEMP in 21 individuals with vestibular neuritis in air conduction and bone conduction mode. The authors reported abnormal oVEMP (approx 80%) in response to both air conduction stimulation and bone conduction stimulation in individuals with vestibular neuritis, whereas cVEMPs were normal with both air conduction stimulation and bone conduction stimulation. The authors suggested that normal air conduction oVEMP and abnormal air conduction cVEMP could be classified into type 1 (inferior vestibular neuritis), type 2, probable type of superior vestibular neuritis, showing present air conduction cVEMP but loss of air conduction oVEMP, type 3, probable complete vestibular neuritis, without air conduction oVEMP and air conduction cVEMP.

It has been stated that cVEMP and oVEMP recording help to differentiate between saccular and utricular dysfunction in individuals with vestibular neuritis. Govender, Rosengren and Colebatch(2011) recorded the cVEMP and oVEMP using air conducted and bone conducted stimuli in individuals with vestibular neuritis (n=23) and reported that air conduction evoked cVEMP was abnormal in 22% and air conduction oVEMP was 68% whereas BC evoked abnormal response for cVEMP and oVEMP were 74% and 70% in individuals with vestibular neuritis respectively.

Shin et al. (2012) recorded the air-conducted oVEMP and cVEMP in 60 healthy controls and in 41 individuals with acute vestibular neuritis. The vestibular neuritis selectively involved the superior vestibular nerve in 30 individuals, affected the inferior vestibular nerve only in three and damaged both superior and inferior vestibular nerve branches in eight and reported that all 30 individuals with superior vestibular neuritis presented normal cVEMPs, indicating preservation of the saccular receptors and their afferents in the inferior vestibular nerve. However, the oVEMP was abnormal in all individuals with superior vestibular neuritis.

Manzari, Burgess and Curthoys (2012) recorded the vibration conduction of cVEMP and oVEMP in 59 individuals with inferior vestibular neuritis showed abnormal cVEMP and normal oVEMP and suggested that on vibration stimulation, the ocular n10 component indicates utricular function and the cervical p13-n23 component indicates saccular function. Kim and Kim (2012) reported that Cervical VEMP was abnormal in 78% of individuals. Results of the ocular VEMP indicated normal findings in all four individuals tested.

Lin and Young (2011) reported that 19 (95%) of 20 individuals with vestibular neuritis had abnormal caloric responses, 11 individuals (55%) had abnormal oVEMPs and 5 individuals (25%) had abnormal cVEMPs. Murofushi, Nakahara, Yoshimura and Tsuda (2011) reported that individuals with vestibular neuritis (n=6) showed abnormal findings on all individuals (100%) with vestibular neuritis air conduction stimulation oVEMP and caloric tests, only 2 individuals showed abnormal air conduction stimulation cVEMPs and hypothesized that the oVEMP in response to air conduction stimulation reflects utricular functions whereas air conduction stimulation cVEMP reflects saccular function.

Benign paroxysmal positional vertigo (BPPV)

Eryaman et al. (2012) recorded VEMP in individuals with posterior canal BPPV. Authors found that 19 individuals with posterior canal BPPV had normal VEMP, 5 had delayed VEMP response and 7 ears individuals with posterior canal BPPV has absent VEMP whereas presence was found in all 46ears of control group. There was significant difference was found between normal individual and individuals with posterior canal BPPV in VEMP response. Authors concluded that the prolongation of latency of VEMP may show degeneration of macula of saccule and absence VEMP response indicates damage in the saccule.

It has been reported that VEMP is an important tool to diagnose otolith dysfunction in BPPV. Lee et al (2013) recorded oVEMP and cVEMP in 16 individuals with BPPV. Authors found that 31.3% of individuals with BPPV have abnormal cVEMP and 25% individuals with BPPV have abnormal oVEMP response. 50% individuals with BPPV had abnormal VEMP and 15% abnormal VEMP was found in individuals with non- recurrent BPPV.

Latency of VEMP has been used to find the severity and prognosis of BPPV. Yang et al. (2008) recorded VEMP in 41 individuals with BPPV and showed prolonged p13 and n23 latencies in individuals with BPPV and concluded that VEMP latencies are increased in BPPV individuals, which indicates significant neuronal degenerative changes in the macula of the saccule. Based on the results, the authors proposed that VEMP could be a useful method to determine a clinical prognosis of individuals with BPPV.

Wu et al. (2006) recorded VEMP and caloric test in individual with BPPV and found that Vestibular evoked myogenic potential (VEMP) was abnormal in 34 percent (11/32) of cases with BPPV and bithermal caloric test were abnormal in 28 percent (20/72) of cases with BPPV. In the abnormal cases, 67 percent (12/18) of cases were

ipsilateral with BPPV. The majority of the BPPV with abnormal results of bithermal caloric test (89%, 16/18) belong to posterior semicircular canal BPPV.

Nakahara et al. (2013) recorded oVEMP and cVEMP in individuals with BPPV. Authors found that oVEMP response was abnormal in affected side whereas no significant difference was found between individuals with BPPV and control group for cVEMP response. There is no association was found between oVEMP, cVEMP and caloric tests in the diagnosis of individuals with BPPV.

It has been reported that cVEMP also found abnormal due to ageing. Hong et al (2008) recorded VEMP in 53 individuals with BPPV and showed significantly more prolonged p13 and n23 latencies and lower amplitude than the other 2 subgroups. Of the 53 individuals with BPPV, 13 (24.5%) showed abnormal VEMP responses on the affected side when compared with their age-related control subgroup. There was no correlation between VEMP findings and the affected semicircular canal and concluded that individuals with BPPV may show abnormal VEMP findings, irrespective of the involved semicircular canal, and age was associated with VEMP results suggesting degeneration of the maculae of the saccule.

It has also been stated that cVEMP cannot differentiate BPPV from normal healthy individuals. Singh et al (2014) recorded cVEMP in BPPV and responses were analyzed and found no significant difference in the latencies of P13 and N23 between normal controls and individuals with BPPV. Also, there was no significant difference for p13-n23 amplitude between normals and individuals with BPPV. Based on the results, authors reported that cVEMP cannot be utilized for the diagnosis of BPPV.

VESTIBULAR TEST FINDING IN SENSORINEURAL HEARING LOSS

1. **VEMP findings in individuals with SNHL:**

Cushing et al (2013) recorded VEMP, caloric and rotational test in children with severe to profound hearing loss to evaluate saccule and horizontal canal function. Authors found mild abnormal response in caloric test in 50 % of children with severe to profound hearing loss. 37% of children with severe to profound hearing loss had severe hypofunction in caloric response. Rotational test showed abnormal response in 47% of children with severe to profound hearing loss. VOR gain was found to be reduced in 29% of children with severe to profound hearing loss. Bilateral absent VEMP was found in 21% whereas unilateral absence of response in 13% children with severe to profound hearing loss. Authors concluded the dysfunction of vestibular end organ in children with severe to profound hearing loss.

Cushing, Papsin, Rutka, James, & Gordon (2008) assessed horizontal semicircular canal and saccule function in children with sensorineural hearing loss by recording caloric, rotational and VEMP in children with sensorineural hearing loss. Mild to moderate unilateral abnormalities was found in caloric response in 50 % of children with sensorineural hearing loss whereas 38% of children with sensorineural hearing loss had abnormal rotational response. VEMP response showed bilateral absent response in 19% and absent unilateral VEMP in 19% in children with sensorineural hearing loss. Authors concluded vestibular dysfunction in more than 1/3 of children with sensorineural hearing loss.

Sazgar, Dortaj, Akrami, Akrami, & Yazdi(2006) recorded VEMP to assess saccule functioning in 50 individuals with high frequency sensorineural hearing loss with different degree. Authors found that individual with high frequency sensorineural hearing loss greater that 40 dBHL has absence of VEMP response. Therefore, authors suggested subclinical damage on the saccule function in individual

with high frequency hearing loss that showed that the same factors are affecting both the cochlea and saccule simultaneously.

Hong et al.,(2008) assessed functioning of saccule in individual with sudden sensorineural hearing loss by recording VEMP and found that absence of VEMP in higher degree of hearing loss whereas presence of VEMP in hearing loss less than 55dB. Authors concluded that the individual with sudden sensorineural hearing loss may have subclinical damage of saccule.

Chen & Young (2006) assessed VEMP in idiopathic sudden deafness and found abnormal VEMP in 21% of individuals. Wang and Young (2007) recorded caloric test and VEMP in 20 individuals with chronic noise-induced hearing loss. Authors found abnormal caloric response in 45% of individual and absence of VEMP in 50% of individuals with chronic noise-induced hearing loss. Combination of VEMP and caloric response in individuals with chronic noise-induced hearing loss together showed 70% of abnormality. Therefore authors concluded the damage of sacculocollic reflex pathway in individuals with chronic noise-induced hearing loss

Bansal, Sahni, & Sinha (2013) assessed the functioning of saccule and utricle in 20 individuals with severe to profound hearing loss by recording of cVEMP and oVEMP. Authors found that presence of cVEMP and oVEMP in 100% and 66% respectively in individual with severe to profound hearing loss. Therefore authors suggested of more utricular dysfunction in individual with severe to profound hearing loss than saccule function.

vHIT findings in individuals with SNHL:

Jutila, Aalto and Hirvonen (2013) horizontal VOR gain and asymmetry ratio were calculated in 44 adults with preoperatively who were receiving Cochlear implants and gain was found to be 0.77 ± 0.26 preoperatively, 0.75 ± 0.30 in the early

and 0.73 ± 0.33 in the late postoperative control, and did not change significantly and mean asymmetry was 9% to 10%.Authors concluded that late high-frequency loss of vestibular function or vestibular symptoms is rare but possible after cochlear implantation surgery. This should be taken into account in patient counseling especially when considering bilateral cochlear implant surgery.

Ichijo, Satio, Fujita and Shinkawa (1995) assessed vestibular function in 5 individuals with progressive hearing loss using electronystagmography. Bilateral reduction of caloric response and very low vestibulo-ocular reflex (VOR) gain on rotation testing were observed in Cases 1, 2 and 3. Case 4 showed right canal paresis upon the caloric test and left directional preponderance upon the rotation test. Case 5 showed good responses to both tests

Clinical applications of video head impulse test (vHIT) of peripheral vestibular disorders:

1. **Meniere's disease**

Zhang et al. (2015) performed vHIT in 23 ears in individuals with Meniere's disease and reported abnormal incidence of vHIT in 21 ears. The authors concluded that vHIT results help to discriminate peripheral vertigo due to Meniere's disease that from central vertigo. The authors also concluded that vHIT can be performed in easy way without any adverse reactions and can record vestibular – ocular reflex for the six semicircular canals in individuals with Meniere's disease.

Martinez-Lopez et al. (2015) reported and individuals with Meniere's disease suffering from an attack of vertigo, ear fullness and in tinnitus in left ear. The client was assessed using vHIT for the possible dysfunction in the semicircular canals. The authors found that the vHIT responses were affected in LARP (left anterior and right posterior plane) in the individual. The testing was repeated three times but the same

result was obtained all the three times. The authors concluded that the vHIT can be a useful tool for the diagnosis of semicircular canal dysfunction in individuals with Meniere's disease.

McGarvie et al. (2015) tested 22 individuals with Meniere's disease using vHIT to look for possible dysfunction of the semicircular canal. The authors reported that the data of the Meniere's ear could not be differentiated from non-Meniere's ears based on the results of the vHIT test. McCalsin et al (2015) recorded vHIT in three individuals with Meniere's disease. The vHIT was administered only for the horizontal planes. The authors reported that the VOR gain value was normal for all the three individuals with Meniere's disease. There was no change in VOR gain value the individuals with Meniere's disease. Further, there was dissociation between the results of the vHIT and caloric test. The authors concluded that the semicircular canal function may not be affected in these three individuals with Meniere's disease.

Rambold (2015) recorded vHIT and bithermal caloric irrigation on the same day in 1063 individuals with Meniere's disease. The authors found that abnormal vHIT was obtained in 4.6% of the individuals with Meniere's disease, 13.3 % of the individuals with Meniere's disease had abnormal vHIT and caloric test findings and 24.1% of the individuals with Meniere's disease had abnormal caloric test response. The authors concluded that the vHIT aids in to the diagnosis of the Meniere's disease and vHIT also saves the time in diagnosis of such cases.

vHIT help to evaluate the change in VOR response after the intratympanic gentamicin for Meniere's disease. Marques et al. (2015) assessed angular vestibular-ocular reflex (VOR) changes after treatment with intratympanic gentamicin for 31 individuals with Ménière's disease. The VOR gain was measured for all the individuals with pre and post gentamicin therapy. The authors found that the VOR

gain reduces significantly after administration of gentamicin in individuals with Meniere's disease. The authors concluded that the vHIT can assess the condition of semicircular canals status in individuals with Meniere's disease.

Zulueta-Santos et al. (2015) did retrospective study in individuals with Menier's disease after treatment with intra- tympanic dexamethason and stimulate the six SCCs to correlate the clinical findings to elicit vestibular –ocular reflex. 30 individuals were included. Vestibular-ocular reflex gain averages in the treated ear after treatment were 0.73 (superior semicircular canal), 0.86 (horizontal semicircular canal), and 0.69 (posterior semicircular canal). The gain did not vary significantly between the superior, the horizontal, or the posterior semicircular Canal. Similar results were obtained for the untreated ear.

2. Vestibular neuritis

Blödow, Pannasch, & Walther (2013) recorded VOR gain of horizontal semicircular canal in 52 individuals with vestibular neuritis using vHIT. Authors found that VOR gain was abnormal in 94.2% of individuals with vestibular neuritis. Refiaxtion saccades were also seen in individual with vestibular neuritis. Therefore authors concluded that vHIT is able to detect abnormal horizontal canal function with combination of VOR gain and refixation saccades.

MacDougall, Weber, McGarvie, Halmagyi, & Curthoys (2009) recorded vHIT in 6 individuals with vestibular neuritis. Authors compared the vHIT and search coil recordings of eye movements. Authors found that measured mean VOR gains with vHIT and search coils were not significant difference in both normals and individuals with vestibular neuritis. Authors concluded that vHIT measures both overt and covert saccades accurately and it is easier to use to identify peripheral vestibular disorders.

Walther & Blödow (2013) recorded vHIT in 20 individuals with unilateral vestibular neuritis and also compared oVEMP and cVEMP response. Authors classified the different types of vestibular neuritis with the probable involvement of semicircular canals and otolith organs. Authors found that air conduction stimulation of oVEMP and cVEMP with 500Hz stimuli with combination of vHIT help to differentiate four types of vestibular neuritis. Entire vestibular neuritis, superior vestibular neuritis was found in majority of individuals with acute vestibular neuritis and 15% was diagnosed as inferior vestibular neuritis and 25% with ampullary vestibular neuritis. Therefore authors concluded that site of lesions for entire vestibular neuritis, superior vestibular neuritis, inferior vestibular neuritis, ampullary vestibular neuritis which may be complete or partial could be diagnosed with the help of cVEMP, oVEMP and vHIT.

Redondo-Martínez et al (2015) measured VOR gain asymmetry and canal paresis using vHIT and caloric response respectively in 20 individuals with vestibular neuritis. Authors found no linear correlation between vHIT and caloric measurement and concluded that these two tests stimulate at different frequencies of vestibule-ocular reflex. Therefore, vHIT complement with caloric for the diagnosis of vestibular neuritis

Yoo et al (2015) performed caloric test and vHIT in 23 individuals with vestibular neuritis. Authors found that caloric and vHIT responses in individuals with vestibular neuritis are affected and also there is significant positive correlation between these two tests. Authors concluded that caloric and vHIT stimulate different frequencies of head movement to elicit VOR response and provide complementary information regarding the functioning of horizontal semicircular canal.

Magliulo, Iannella, Gagliardi, & Re (2015) recorded cVEMP, oVEMP and vHIT in 40 individuals with vestibular neuritis. Authors found absence of oVEMP in 32 individual with vestibular neuritis and absence of cVEMP in 19 individual with vestibular neuritis. Horizontal semicircular canals and superior semicircular canal deficit was found in 35 and 31 individual with vestibular neuritis.19 of the 40 individual with vestibular neuritis had abnormal posterior semicircular canal. Authors concluded that cVEMP, oVEMP and vHIT are vestibular diagnostic protocol to identify different type of vestibular neuritis.

Magliulo, Gagliardi, Ciniglio Appiani, Iannella, & Re (2014) recorded cVEMP , oVEMP and vHIT in 40 individuals with vestibular neuritis. Authors found that 55% of individuals had superior and inferior vestibular neuritis, 40% were superior vestibular neuritis, and 5% individuals had inferior vestibular neuritis. 40 of the 4 individuals with vestibular neuritis had abnormality in horizontal and superior semicircular canals. Authors concluded that cVEMP, oVEMP and vHIT all together can be included in test battery to diagnose peripheral vestibular disorders.

Bartolomeo et al (2014) recorded video head impulse test and caloric test in 29 individual with vestibular at initial stage and the follow-up visit. Authors found that higher deficit in caloric test that vHIT in initial presentation whereas 51.8% had normal vHIT and 31% had normal caloric response in follow-up visit. Authors concluded that 100% specificity and sensitivity of vHIT when caloric deficit was less that 40% and higher that 62.5%. Also, authors stated that vHIT is fast and convenient test to detect the lesion in individual with vestibular neuritis.

3. Benign paroxysmal positional vertigo (BPPV)

Chen et al(2012) evaluated 214 individuals with beningn paroxymal positional vertigo in which 107 individuals had posterior semicircular canal

canalthiasis and 27 individuals with horizontal semicircular canal cupulothiasis and 80 individuals with horizontal semicircular canal canalthiasis.Diffrent frequency vestibular function tests with high , mid and low frequencies head movmement which includes vHIT, head shaking test and caloric test was recorded in all individuals with beningn paroxymal positional vertigo. Authors found that 7% of individual with beningn paroxymal positional vertigo had abnormal vHIT , 24% individual with beningn paroxymal positional vertigo had abnormal head shaking test whereas caloric test showed abnormality in 71 % of individual with beningn paroxymal positional vertigo. Authors concluded that low frequency of semicircular canal frequncy tests are sensitve to find BPPV and vHIT cannot be used to evaluate semicircular function in BPPV.

To summarise, the review, vHIT test is a new tool to assess the vestibular dysfunction in individuals with vestibular disorders. The studies in the literature related to vHIT have just started to appear and very few studies have been conducted in pathological population. Further, studies related to VOR gain in individuals with sensorineural hearing loss is very less. Therefore, there is a need to conduct the vHIT study in senorineural hearing loss in order to understand the mechanism underlying various vestibular pathologies in individuals with sensorineural hearing loss.

Chapter-3
METHOD

The study was conducted with the aim of the study to objectively assess the functioning of otolith organs (saccule and utricle) and three semicircular canals in individuals with severe to profound sensorineural hearing loss using cVEMP, oVEMP and vHIT respectively.

Participants:

Study consisted of two groups, Group-I consisted of 20 adult participants (40 ears) having severe to profound hearing loss ranging in age from 15-40 years. Group-II consisted of 20 adult participants (40 ears) in the age range from 15-40 years with normal hearing sensitivity.

Participant selection criteria

Group-I:

- All the participants had bilateral severe to profound sensorineural hearing loss.
- All the participants had normal middle ear function as evidenced by the immittance evaluation.
- Participants did not have any history or presence of any ear pain or ear discharge.
- Participants had UCL for speech should be greater than 100 dBHL in both the ears.
- Participants did not have any associated neurological problems.
- Participants did not have any history of neuromuscular problems in neck region.
- Participants did not have any history or presence of any obvious vestibular pathology such as Meniere's disease, labyrinthitis.

Participants selection criteria for Group-II:

- All the participants had bilateral normal hearing sensitivity.
- Participants did not have presence of conductive hearing loss.
- Participants did not have history of neuromuscular problems in body and neck region
- Participants did not have history or presence of neurological problems.
- Participants did not have history or presence of any ear pain, ear discharge.
- Participants did not have uncomfortable loudness level problems.
- Participants did not have vestibular sign and symptoms.

Instrumentation:

- Calibrated GSI-61 audiometer with TDH-39 headphone encased in MX-41/AR supra-aural cushion was utilized for estimation of air conduction pure tone thresholds.
- Bone conduction threshold was estimated using Radio ear B-71 bone vibrator.
- Middle ear status was evaluated by using a calibrated Grason-Stadler Tympstar(GSI) middle ear analyser.
- Bio-Logic Navigator Pro System was used to record vestibular evoked myogenic potentials (VEMP) and
- Video head impulse tests were all carried out with prototype ICS impulse video goggles (GN Otometrics, Taastrup, Denmark), with a camera speed of 250frames/s, recording motion of the right eye.
- All the measurement was carried out in an acoustically treated double room situation

Test Environment

All the testing was carried out in an acoustically and electrically shielded room where the levels was within the permissible limits (ANSI S3.1; 1991).

Test Procedure

- ❖ Written consent was taken from all the subjects.
- ❖ Pure-tone thresholds was obtained for all the participants using modified version of Hughson and Westlake procedure (Carhart & Jerger, 1959) at octave frequencies between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction.
- ❖ UCL was obtained in both ears for air conducted speech stimuli using ascending method.
- ❖ Immittance audiometry was carried out in both ears using a probe tone frequency of 226 Hz.
- ❖ Tympanometry was done initially and then ipsilateral and contralateral acoustic reflex threshold was measured for 500, 1000, 2000, and 4000 Hz stimuli.

Cervical Vestibular evoked myogenic potentials (cVEMP) :

cVEMP was recorded from all the participants. Prior to cVEMPs recording the electrode sites was cleaned with abrasive gel (Nuprep). The silver chloride disc type of electrodes was placed on the electrode sites with adequate amount of conduction paste. Surgical tape was used to hold the electrode on the electrode sites. *Absolute electrode impedances and inter electrode impedances was maintained below 5000 ohms and 2000 ohms respectively.* During the cVEMPs recordings the participants was instructed to sit straight and turn their head to the opposite side of the ear in which stimulus was presented, so as to activate ipsilateral sternocleidomastoid (SCM) muscle, as it gives reliable and greater amplitude. Participants were instructed to

maintain the same posture throughout the test run. The stimulus and acquisition parameters used to record c- VEMP are given in Table-3.1

Table 3.1:

Parameters for recording c-VEMP

Stimulus Parameters	
Stimulus	**Settings**
Transducer	Insert ear phones
Type	Tone burst
Frequency	500 Hz
Intensity	125dBSPL
Duration	2-1-2 Cycles
Acquisition Parameters	
Stimulus polarity	Rarefaction
Stimulus Rate	5.1/s
Time window	
Pre stimulus	10 msec
Post stimulus	60 ms
Filter setting	30 to 1500 Hz
Amplification	5000
No of Sweeps	150
No. of recording	2
Electrode Placement	
Inverting electrode (-)	Sternoclavicular junction
Non inverting electrode (+)	Sternocleidomastoid muscle
Ground electrode	Forehead

Ocular Vestibular evoked myogenic potentials (oVEMP):

For oVEMPs recordings, the electrode sites were cleaned with abrasive gel (Nuprep). The silver chloride disc type of electrodes was placed on the electrode sites with adequate amount of conduction paste. Surgical tape was used to hold the electrode on the electrode sites. *Absolute electrode impedances and inter electrode impedances was maintained below 5000 ohms and 2000 ohms respectively*. oVEMPs was recorded for all the participants with upper gaze direction. Participants were instructed to maintain the same upper gaze throughout the test run. The stimulus and acquisition parameters used to record o- VEMP are given in Table-3.2

Table 3.2

Parameters for recording o- VEMP

Stimulus Parameters	
Stimulus	**Settings**
Transducer	Insert ear phones with 0.8ms delay
Type	Tone burst
Frequency	500 Hz
Intensity	125dBSPL
Duration	2-1-2 Cycles
Acquisition Parameters	
Stimulus polarity	Rarefaction
Stimulus Rate	5.1/s
Time window	
Pre stimulus	10 ms
Post stimulus	60ms
Filter setting	1 to 1000 Hz
Amplification	30000
No of Sweeps	150
No. of recording	2
Electrode Placement	
Inverting electrode (-)	1 cm below eye on inferior oblique muscle
Non inverting electrode (+)	Immediately inferior to inverting electrode
Ground electrode	Forehead

Video heed impulse test (vHIT):

Video head impulse test as carried out in well lit room. Target was kept at the eye-level at a distance of 1 m in front of participants. Participants were seated on a height adjustable, rotatable chair was used to maintain ideal height for clinician to deliver horizontal or vertical impulses. vHIT goggles were tightened on the head of each participant to minimize goggles slippage. The target was fixed according to the participant height. Participants were fixated on two projected laser dots separately for calibration of eye position signal. Once calibration was done then participants were instructed to maintain their gaze at the target object, which was located at the eye level beyond the camera at a distance of 1 m straight ahead. A clinician stood behind each participant and rotated the head in horizontal planes in right and left direction. For LARP and RALP positions, the clinician moved the head of the participant upward and downward plane towards right and left side. Each participant underwent a minimum of 20 head impulses in each plane and in each direction. The head was rotated manually and abruptly in each plane at an angle of 10–20 and was randomized. A high speed digital infrared camera which is a part of the instrument was utilized to record the eye movement during and immediately after the head rotation. Mean VOR gain was calculated by taking the average VOR gain of 20 trials in each plane. VOR gain calculation for 20 trials in each plane provides a good response and good test-retest reliability in normal hearing individuals (Bansal & Sinha, 2016).

Response Analysis

The various parameters of cVEMP, oVEMP and vHIT were analysed for both the groups and are given as follows:

1. **Cervical vestibular evoked myogenic potentials:**

- Latency of p1, n1 was analysed for both the groups.
- Amplitude complex of p1 – n2 was analysed for both the groups.

1. **Ocular Vestibular evoked myogenic potentials:**

- Latency of n1, p1, n2 peaks were analysed for both the groups.
- Amplitude complex of n1-p1 & p1- n2 was analysed.

1. **Video head impulse test:**

- VOR Gain value responses were analysed for both the groups. The values are represented as hexagram as shown in figure-3.1.

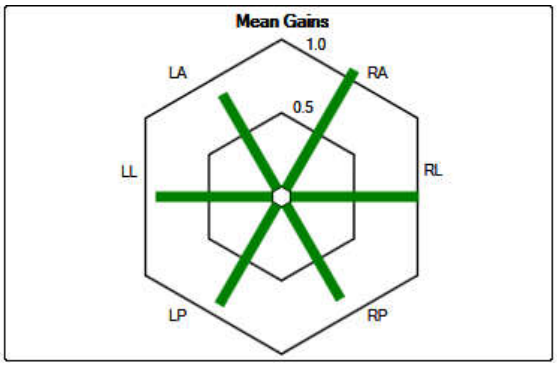

Figure3.1 Hex lateral, anterior and posterior canals.

Chapter 4

RESULTS

Present study was conducted with an aim of assessing the function of otoliths (saccule and utricle) and three semicircular canals in individual with severe to profound sensorineural hearing loss. To achieve the aim, the cervical vestibular evoked myogenic potentials, ocular vestibular evoked myogenic potentials and video head impulse test were administered in individuals with severe to profound sensorineural hearing loss.

Cervical vestibular evoked myogenic potentials (cVEMP)

Latency of p1, n1 peaks, and amplitude of p1-n1 complex of cVEMP were analyzed for both the groups. In normal hearing group cVEMP potential was present in all 40 ears i.e., in 100% of the ears.

In individuals with severe to profound sensorineural hearing loss cVEMP potentials was present in 18 of the 20 in right ear and 15 of the 20 left ears in the present study. Figure 4.1A and 4.1B shows the individual and grand averaged waveform of cVEMP in normal hearing individuals of right and left ear respectively. Figure 4.2A and 4.2 B shows the individual and grand averaged waveform of cVEMP in individuals with severe to profound sensorineural hearing loss of right and left ear respectively.

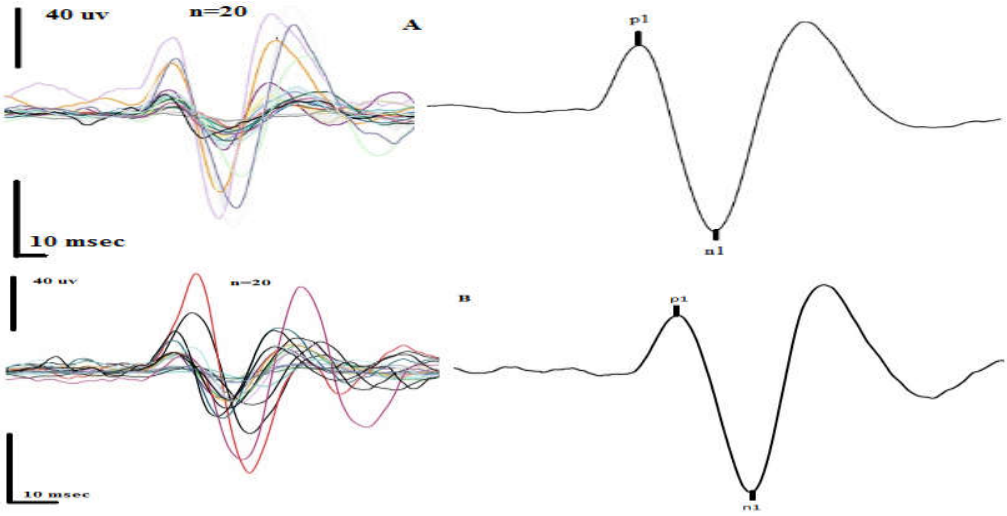

Figure 4.1 A) Shows the individual and the grand averaged cVEMP waveform in normal hearing individuals in right ear B) Shows the individual and the grand averaged cVEMP waveform in normal hearing individuals in left ear. Both the tracing contains a 10 msec pre stimulus time window.

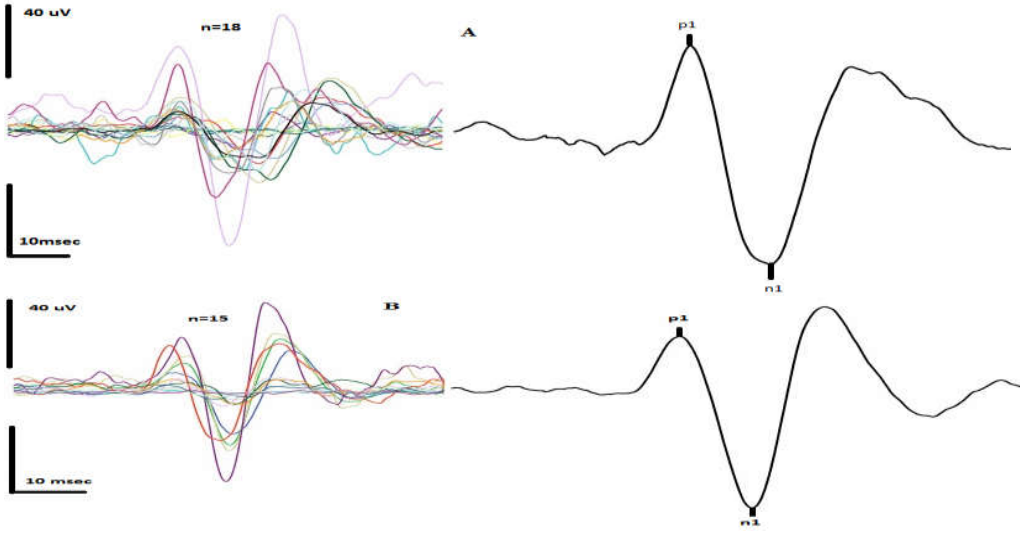

*Figure 4.2*A) Shows the individual and the grand averaged cVEMP waveform in individuals with severe to profound sensorineural hearing loss in right ear B) Shows the individual and the grand averaged cVEMP waveform in individuals with severe to profound sensorineural hearing loss in left ear. Both the tracing contains a 10 msec pre stimulus time window.

Descriptive statistics was done to calculate the mean and standard deviation for the latency and amplitude of cVEMP parameters for both the ears in normal hearing individuals and individuals with sever to profound sensorineural hearing loss. The values of mean and standard deviation for p1 latency, n1 latency and p1-n1 amplitude complex of both the groups are shown in Table -4.1.

Table 4.1

Mean, standard deviation (SD)and median and Interaural asymmetry ratio for cVEMP potential of individual with normal hearing of right and left ears and individual with severe to profound hearing loss of right and left ears

cVEMP (Normal hearing)	**Right ear with N=20**			**Left ear N=20**			**Interaural asymmetry ratio**
	Mean	**SD**	**Median**	**Mean**	**SD**	**Median**	
p1 Latency[msec]	14.30	0.55	14.32	14.33	0.35	14.32	
n1 Latency[msec]	22.19	0.70	22.31	22.36	0.50	22.31	
p1-n1 amplitude [µV]	73.45	66.6	60.91	59.29	48.47	50.91	10.83
cVEMP (Individual with severe to profound hearing loss)	**Right ears N=18**			**Left ears N=15**			

	Mean	SD	Median	Mean	SD	Median	
p1 Latency[msec]	14.40	1.15	14.32	14.66	1.06	14.42	
n1 Latency[msec]	22.18	1.44	22.13	21.90	1.03	21.83	
p1-n1 amplitude [µV]	41.15	43.64	26.40	47.56	49.74	29.40	7.22

It can be seen that mean latencies of p1, n1 of cVEMP potential of individual with severe to profound sensorineural hearing loss is almost similar to normal hearing individuals in both the ears. However, the amplitude of p1-n1 complex in individual with normal hearing is more than individual with severe to profound sensorineural hearing loss.

The obtained data was tested for normality distribution. *Shapiro–Wilk test* was done for normality check and it showed a non – normal distribution of data ($p<0.05$). Therefore non- parametric statistics was done for the entire data.

Further to understand the significant differences, in mean latency and amplitude of different parameters between the two groups of different ears Mann-Whitney U Test was done. The test revealed no significant difference between group 1 and group 2 for latency of p1 of right ear for [$z = 0.19$, $p>0.05$], latency of n1 [$z= 0.47$, $p>0.05$] and amplitude complex of p1-n1 [$z= 1.80$, $p>0.05$].

For left ear of two groups, Mann-Whitney U test revealed no significant difference between group 1 and group 2 for latency of p1 [$z = 0.81$, $p>0.05$] and amplitude complex of p1-n1 [$z= 1.23$, $p>0.05$], however a significant difference was observed between the two groups for latency of n1 [$z= 2.00$, $p<0.05$].

Further to find out the significant differences between the two ears data, Wilcoxson signed rank test was done. The results of the Wilcoxson signed rank test is given in Table 4.2

Table 4.2

Wilcoxon signed ranks test in individual with severe to profound hearing loss and individual with normal hearing of cVEMP to compare the ear differences

cVEMP	**Rp1-Lp1**	**Rn1-Ln1**	**Rp1n1-Lp1n1**
z value	0.38	1.16	0.07
p value	0.70	0.25	0.08

Rp1: p1 latency of right ear, Lp1:p1 latency of left ear, Rn1:n1 latency of right ear, Ln1:n1 latency of left ear, Rp1n1: p1n1 amplitude complex of right ear, Lp1n1: p1n1 amplitude complex of left ear

Since there were no differences between the data of the two ears for any of the cVEMP parameters, the data of the two ears were combined. Descriptive statistics was done for the overall data to calculate the mean and standard deviation for the latency and amplitude of cVEMP parameters. The values of mean and standard deviation for p1 latency, n1 latency and p1-n1 amplitude complex are shown in table - 4.3.

Table-4.3

Mean and standard deviation for cVEMP potential of individual with normal hearing and Severe to Profound sensorineural hearing loss [SNHL]

cVEMP	**Severe to Profound SNHL (Group1) N=33**			**Normal hearing (Group2) N=40**		
	Mean	SD	Median	Mean	SD	Median
p1 Latency[msec]	14.51	1.11	14.32	14.31	0.46	14.31
n1 Latency[msec]	22.06	1.26	21.83	22.26	0.60	22.31
p1-n1 amplitude [µV]	45.51	4.7	26.4	64.79	5.84	50.9

It can be seen from Table-1 that mean latencies of p1, n1 of cVEMP potential of individual with normal hearing is almost similar to individual with severe to profound sensorineural hearing loss. However, the amplitude complex of p1-n1 in individual with normal hearing are larger than individual with severe to profound sensorineural hearing loss.

Further to understand the significant difference in mean latency and amplitude of different parameters of overall data, between the two groups, Mann-Whitney Test was done. Mann-Whitney test revealed no significant difference between group 1 and group 2 for latency of p1 [z = 0.40, $p>0.05$]. However, the Mann-Whitney test showed a significant difference for latency of n1 [z= 2.20, $p<0.05$] and amplitude complex of p1-n1 [z= 1.91, $p<0.05$] between group 1 and 2. To summarise, for the latency of p1 there was no significant difference between the two groups, however

latency of n1 and the amplitude of n1-p1was significantly lower for group 1 compared to group 2.

Ocular vestibular evoked myogenic potentials (oVEMP)

Latency of n1, p1 and n2 peaks, n1-p1 amplitude complex of oVEMP was analyzed. oVEMP was present in all 40 ears i.e., in 100% of the ears in individual with normal hearing.

In individual with severe to profound sensorineural hearing loss oVEMP potentials were present in 11 of the 20 right ears and 12 of the 20 left ears in the present study. Figure 4.3A and 4.3B shows the individual and grand averaged oVEMP waveform in normal hearing individuals, whereas 4.4A and 4.4B shows the waveforms of oVEMP in individuals with severe to profound sensorineural hearing loss.

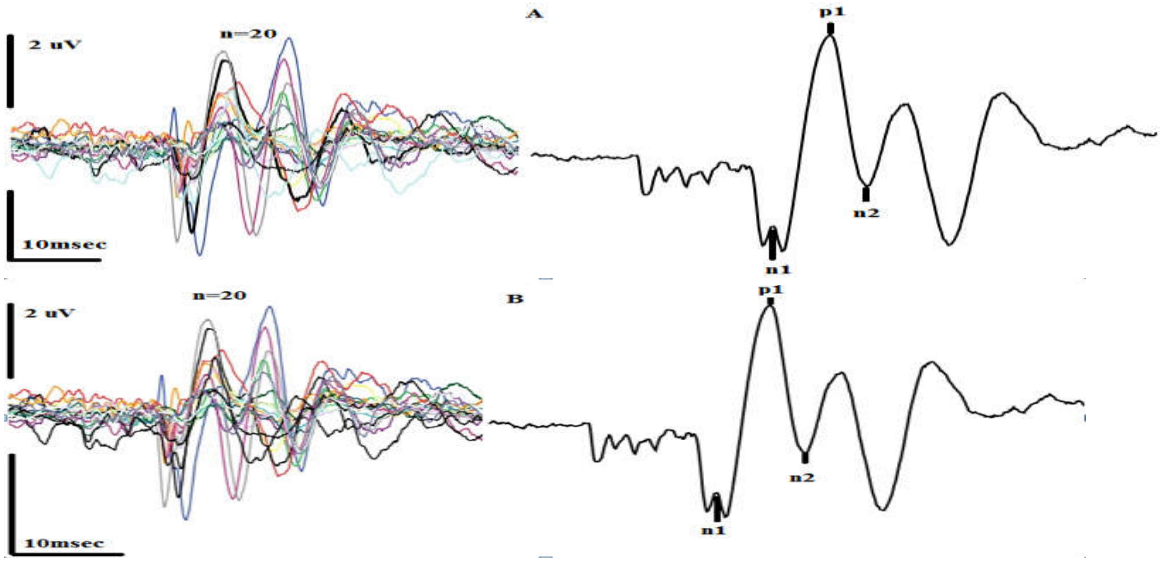

Figure 4.3 A) Shows the individualand the grand averaged oVEMP waveform in normal hearing individuals in right ear B) Shows the individual and the grand averaged oVEMP waveform in normal hearing individuals in left ear. All the tracings include a 10 msec prestimulus time window.

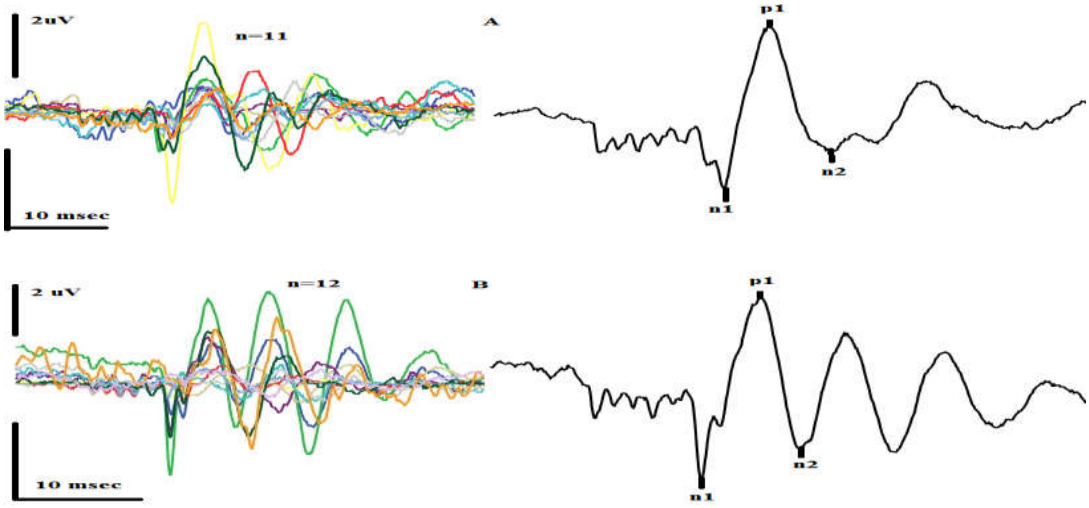

Figure 4.4 A) Shows the individual and the grand averaged oVEMP waveform in severe to profound hearing loss individuals in right ear B) Shows the individual and the grand averaged oVEMP waveform waveform in severe to profound hearing loss individuals in left ear. All the tracings include a 10 msec prestimulus time window.

Descriptive statistics was done to calculate the mean, standard deviation for the latency and amplitude of oVEMP parameters for both the groups of right and left

ears. The values of mean and standard deviation for n1 latency, p1 latency, n2 latency, n1-p1 amplitude complex of normal hearing of both the ears and individual with severe to profound sensorineural hearing loss of both the ears are shown in Table 4.4.

Table 4.4

Mean, standard deviation, median and inter amplitude difference for oVEMP potential of individual with normal hearing of right and left ears and individual with hearing loss of right and left ears

oVEMP (Individual with normal hearing)	**Right Ears N=20**			**Left Ears N=20**			**Interaural asymmetry ratio**
	Mean	SD	Median	Mean	SD	Median	
n1 Latency[msec]	10.48	0.42	10.40	10.56	0.33	10.50	
p1 Latency[msec]	15.55	0.47	15.45	15.69	0.67	15.50	
n2 Latency(msec)	20.43	0.64	20.45	20.83	0.66	20.75	
n1-p1amplitude [μV]	3.75	2.93	2.92	5.38	7.17	4.65	17.85
p1-n2amplitude [μV]	3.03	5.17	1.93	3.24	1.86	2.56	3.35
oVEMP (Individual with severe to	**Right ears N=11**			**Left ears N=12**			**Interaural asymmetry ratio**

profound hearing loss)							
	Mean	SD	Median	Mean	SD	Median	
n1 Latency[msec]	10.64	1.59	1.057	10.84	1.58	10.78	
p1 Latency[msec]	15.62	1.48	15.83	15.67	1.68	15.98	
N2 Latency(msec)	20.55	0.92	20.70	20.73	1.00	20.85	
N1-p1amplitude [µV]	2.04	1.83	1.20	1.49	1.08	1.35	15.58
p1-n2amplitude [µV]	2.96	4.09	1.18	1.36	1.63	1.21	37.03

It can be seen from Table-4 that mean latencies of n1, p1 and n2 of oVEMP potential of individual with normal hearing is almost similar to individual with severe to profound sensorineural hearing loss. However, the amplitude complex of n1-p1 in individual with normal hearing are larger than individual with severe to profound sensorineural hearing loss.

The obtained data was tested for normality distribution. *Shapiro–Wilk test* was done for normality check and it showed a non – normal distribution of data ($p<0.05$). Therefore non- parametric statistics was done.

Further, to understand the significant difference in mean latency and amplitude of different parameters between the two groups of right ear, Mann-Whitney U Test was done. Mann-Whitney test revealed no significant difference between group 1 and group 2 for latencies of n1 [z = 0.62, *p*.0.05], p1 [z= 1.17, *p*>0.05], latency of n2 [z= 0.35, *p*>0.05], amplitude complex of p1-n1 [z= 1.73, *p*>0.05] and amplitude complex of n2-p1 [z= 0.43, *p*>0.05].

For left ear of two groups, Mann-Whitney U Test revealed no significant difference between group 1 and group 2 for n1 latency [z = 0.21, *p*>0.05], p1 latency [z = 0.89, *p*>0.05], n2 latency [z = 0.74, *p*>0.05] whereas significant difference was observed for amplitude of n1p1complex of [z = 2.88, *p*<0.05] and p1n2 [z= 2.27, *p*<0.05].

Further to understand the ear differences for different parameters of oVEMP, Wilcoxon signed rank test was done to find out the significant difference between right and left side of oVEMP parameters. The results of Wilcoxson signed rank test are given in Table 4.5

Table 4.5

Wilcoxon signed ranks test in individual with severe to profound hearing loss and individual with normal hearing of oVEMP

oVEMP	**Rn1- Ln1**	**Rp1 - Lp1**	**Rn2 - Ln2**	**Rn1p1 - Ln1p1**	**Rn2p1 - Ln2p1**

p value	0.72	0.54	0.60	0.37	0.25
z value	1.16	1.76	0.35	0.61	0.53

Rn1: n1 latency of right ear, Ln1:n1 latency of left ear, Rp1:p1 latency of right ear, Lp1:p1 latency of left ear, Rn2: n2 latency of right ear, Ln2: n2 latency of left ear, Rn1p1: n1p1 amplitude complex of right ear, Ln2p1: n2p1 amplitude complex of left ear

Wilcoxson signed rank test revealed no significant differences for any of the parameters of oVEMP for the two groups, hence the data of the two ears for both the groups were combined. Descriptive statistics was done to calculate the mean and standard deviation of overall combined data for latency and amplitude of oVEMP parameters in group 1 and group 2. The values of mean and standard deviation for n1 latency, p1 latency, n2 latency, n1-p1 amplitude complex of normal hearing and individual with severe to profound sensorineural hearing loss are shown in Table -4.6.

Table-4.6

Mean and standard deviation for oVEMP potential of individual with normal hearing and Severe to Profound sensorineural hearing loss [SNHL]

oVEMP	**Severe to Profound SNHL (Group1) N=23**			**Normal hearing (Group2) N=40**		
	Mean	SD	Median	Mean	SD	Median
n1 Latency[msec]	10.75	1.55	10.57	10.53	0.37	10.40
p1 Latency[msec]	15.65	1.55	15.83	15.64	0.58	15.45

n2 Latency[msec]	20.68	0.94	20.70	20.63	0.68	20.45
n1-p1 Complex amplitude [µV]	2.18	2.96	1.20	3.47	2.46	2.92
p1-n2 Complex amplitude [µV]	1.69	1.73	1.18	3.73	5.57	1.90

It can be seen from Table-2 that mean latencies of n1, p1 and n2 of oVEMP potential of individual with normal hearing is almost similar to individual with Severe to Profound sensorineural hearing loss. However, the amplitude complex of n1-p1 in individual with normal hearing are larger than individual with severe to profound sensorineural hearing loss.

Further to understand the significant difference in mean latency and amplitude of different parameters for combined data between the two groups, Mann-Whitney Test was done. Mann-Whitney test revealed no significant difference between group 1 and group 2 for latencies of n1 [z = 0.71, *p*.0.05], p1 [z= 1.31, $p>0.05$], n2 [z= 0.932, $p>0.05$]. However, the Mann-Whitney test showed a significant difference for amplitude complex of p1-n1 [z= 3.49, $p<0.05$] between group 1 and 2. To summarise, for the latency of n1, p1 and n2 there was no significant difference between the two groups, however the amplitude was significantly lower for group 1 compared to group 2.

Video head impulse test (vHIT)

Mean VOR gain was analyzed in vHIT for both the groups. All individual with normal hearing had normal VOR gain for all six SCC's. Mean VOR gain of one individual with normal hearing is shown in fig: 4.5.

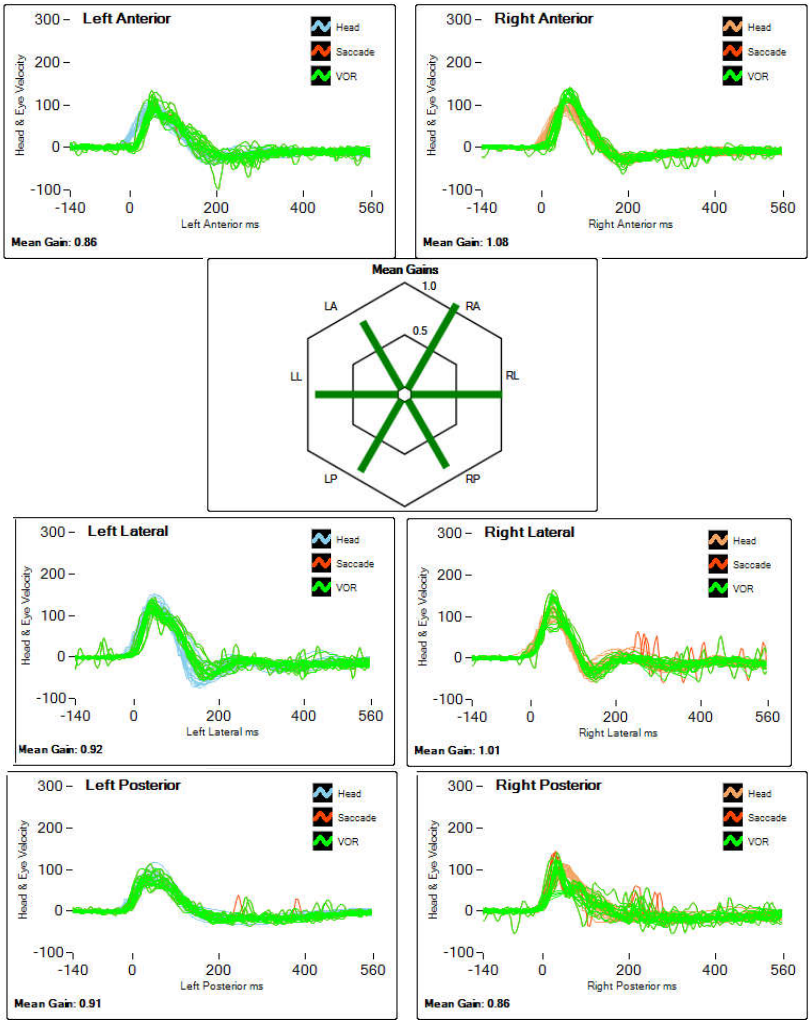

Figure 4.5 Video head-impulse test results in 3 different planes of a individual with normal hearing participant. The head and eye velocities throughout different head impulses to the right or left side are shown. Also, the VOR gain values are shown in the in the form of Hexaplot.

Individual data was analyzed for individual with hearing impaired and found that mean VOR gain for left anterior canal was reduced for 5 individuals and increased for 2 individuals. Mean VOR gain for right anterior canal was reduced for 6 individuals, left lateral canal was reduced for 6 individuals, left lateral canal was reduced for 6 individuals, right lateral canal was reduced for 7 individuals, left posterior canal was reduced for 3 individuals and left posterior canal was reduced for 5 individuals and increased for 3 individuals. Mean VOR gain of for individual with

hearing impaired with normal VOR gain and with reduced VOR gain are shown in fig :4.6 and 4.7 respectively.

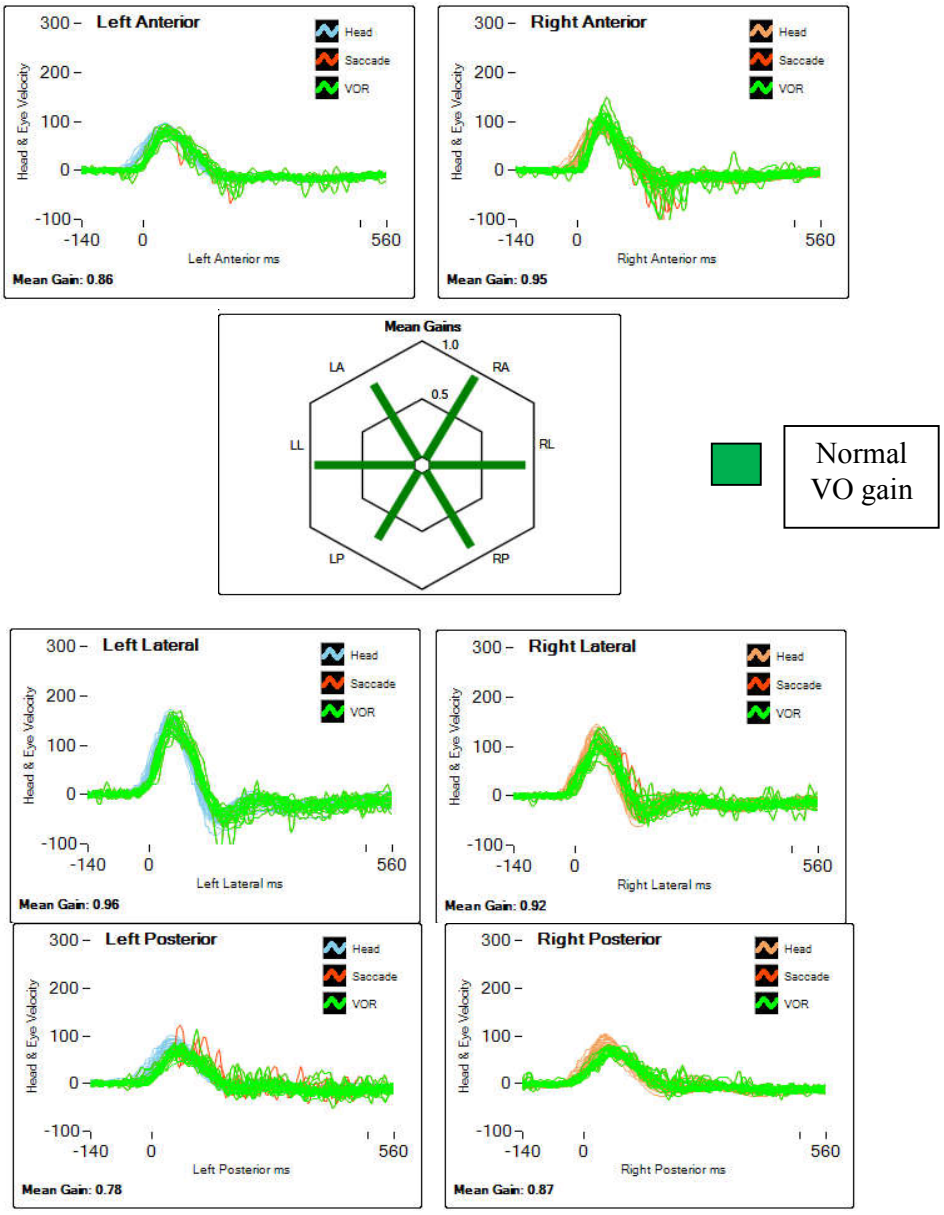

Figure4.6 Video head-impulse test results in 3 different planes of a participant with normal VOR gain in individual with severe to profound hearing loss. The head and eye velocities throughout different head impulses to the right or left side are shown. Also, the gain values are shown in the figure in the form of hexaplot.

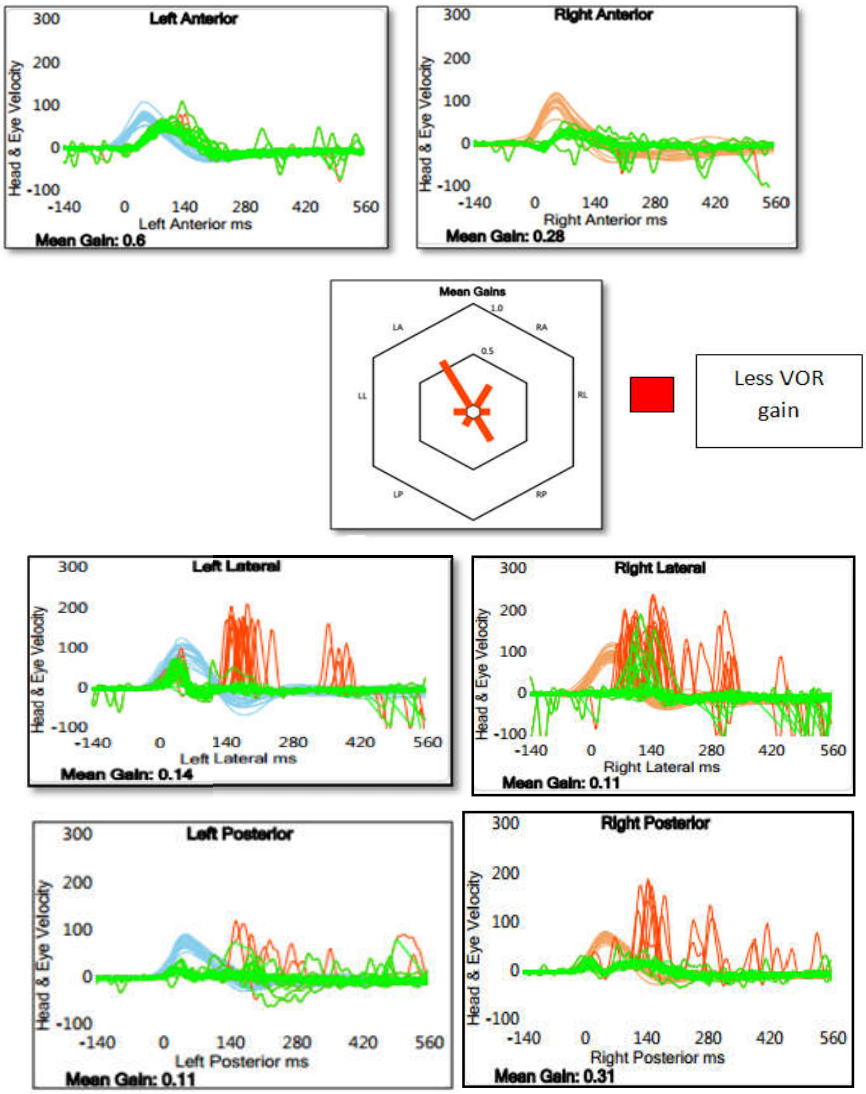

Figure4.7 Video head-impulse test results in 3 different planes of a participant with abnormal VOR gain in individual with severe to profound hearing loss. The head and eye velocities throughout different head impulses to the right or left side are shown. Also, the gain values are shown in the figure in the form of hexaplot.

Descriptive analysis was done to calculate mean and standard deviation of VOR gain in all three planes in both the directions. That is right horizontal (RH), left horizontal (LH), right posterior (RP), left anterior (LA), right anterior (RA), left posterior (LP). Value of VOR gain for both the groups is listed in Table 4.7.

Table 4.7

Mean and standard deviation was calculated for VOR gain for both the groups

	Group 1 (Individual with severe to profound hearing loss)			**Group 2 (Individual with normal hearing)**		
PLANES	Mean	SD	Median	Mean	SD	Median
Right horizontal	0.82	0.24	0.92	1.02	0.11	1.01
Left horizontal	0.76	0.25	0.84	0.95	0.08	0.96
Right posterior	0.88	0.28	0.88	0.87	0.09	0.86
Left anterior	0.90	0.26	0.93	0.89	0.10	0.86
Right anterior	0.83	0.23	0.84	0.92	0.10	0.89
Left posterior	0.81	0.23	0.84	0.90	0.10	0.88

It can be seen from Table-8 that mean VOR gain values for right and left horizontal canals, right anterior and left posterior canal for individual with hearing impaired (Group-1) is lesser than the individual with normal hearing. Mean VOR gain for right posterior and left anterior canal are similar for both the groups.

The obtained data was tested for normality distribution. *Shapiro–Wilk test* was done for normality check and there is no significant difference in the VOR gain of different in individual with severe to profound hearing loss which showed a non – normal distribution of data. Therefore non- parametric statistics was done by using SPSS software.

Wilcoxon rank test was done to find the significant difference between different plane of semicircular canals of individual with normal hearing and individual with severe to profound hearing loss and values are shown is table 4.8.

Table 4.8

Wilcoxon signed ranks test in individual with severe to profound hearing loss and individual with normal hearing

vHIT	**Normal hearing**			**Hearing impaired**		
	LL- RL	LP-RA	LA-RP	LL- RL	LP-RA	LA–RP
z value	1.89	0.14	0.77	2.46	0.78	0.95
P value	0.02	0.43	0.34	0.06	0.89	0.44

LL: Left lateral,RL: Right lateral,LP: Left posterior,RA: Right anterior,LA: Left anterior, RP: Right posterior

There was significant difference found in left and right lateral plane in individual with normal hearing whereas no significant difference was found between the posterior and anterior semi circular canal of both the ears. Also, there was no significant difference found in all three planes of semicircular canal in both the ears in individual with sever to profound hearing loss.

Further to understand the significant difference in mean values of VOR gain between the two groups, Mann-Whitney U Test was done. Mann-Whitney U Test revealed significant difference between group 1 and group 2 for VOR gain for right horizontal canal [$z = 3.07$, $p < 0.05$] and left horizontal canal [$z = 3.01$, $p < 0.05$] whereas no significant difference was showed in right posterior canal [$z = 0.13$,

p>0.05], left anterior canal [z=0.10, *p*>0.05],right anterior canal[z=1.39, *p*>0.05] and left posterior canal [z= 1.02, *p*>0.05].

Association between cVEMP, oVEMP and vHIT:

To find the association between the cVEMP, oVEMP, vHIT chi-square test was done and values are shown in table 4.9.

Table 4.9

Association between cVEMP, oVEMP and vHIT of right ear

Test	**Right cVEMP**				**Right oVEMP**			
vHIT	Present	Absent	Total		Present	Absent	Total	
Right Lateral								
Present	14	1	15		7	8	15	
	4	1	5		4	1	5	
Absent	18	2		20	11	9	20	
Total	0.74*				1.68*			
p- Value*								
Right Posterior								
Present	10	1	11		5	6	11	
	8	1	9		6	3	9	
Absent	18	2		20	11	9	20	
Total	0.02*				0.90*			
p- Value*								
Right Anterior								

Present	12	2	14	6	8	14
Absent	6	0	6	5	1	6
Total	18	2	20	11	9	20
p- Value*	0.95*			2.78*		

(*) Chi-Square Test

From the above table, it was observed that there was association between right posterior plane of vHIT and right cVEMP whereas no association found between cVEMP, oVEMP and different planes of vHIT.

Table 4.10

Association between cVEMP , oVEMP and vHIT of left ear

Test	**Left cVEMP**				**Left oVEMP**			
vHIT	Present	Absent	Total		Present	Absent	Total	
Left Lateral								
Present	9	3	12		6	6	12	
Absent	6	2		8	6	2	8	
Total	15	5		20	12	8	20	
p- Value*	0.00*				1.25*			
Left anterior								
Present	10	3	13		8	5	13	
Absent	5	2	7		4	3	7	
Total	15	5		20	12	8	20	
p- Value*	0.73*				0.03*			
Left posterior								
Present	12	4	16		9	7	16	
Absent	3	1	4		3	1	4	
Total	15	5		20	12	8	20	
p- Value*	0.00*				0.46*			

(*) Chi-Square Test

Form above table, it was observed that there are association between left cVEMP and left lateral plane of vHIT ($p<0.05$), left cVEMP and left posterior plane

of cVEMP ($p<0.05$) and left oVEMP and left anterior plane of vHIT. However, there was no association was found between other test of left ear.

To summarize, cVEMP was present in 100% in both right and left ear of individual with normal hearing whereas 90% and 75% in right and left ear of individual with severe to profound hearing loss respectively. There was no significant difference found for latencies of right ear whereas significant difference was showed in p1-n1 amplitude complex of right ear. However , no significant difference found in the latency of p1 and amplitude complex of p1-n1 of left ear but showed significant difference in latency of n1 of left ear of both the groups.

oVEMP was present in 100% in both right and left ear of individual with normal hearing whereas 55% and 60% in right and left ear of individual with severe to profound hearing loss respectively. There was no significant difference was found between group 1 and group 2 for latencies of n1, p1, n2 and amplitude complex of p1-n1 and p1-n2 of right ear. However, in left ear of group1 and group 2 has found no significant difference between latencies of n1, p1 and n2 whereas significant difference was found between the amplitude complex of n1p1 and p1n2.

In vHIT, it was found that mean VOR gain values for right and left horizontal canals, right anterior and left posterior canal for individual with hearing impaired is lesser than the individual with normal hearing. Mean VOR gain for right posterior and left anterior canal are similar for both the groups. Also, there was significant difference found in left and right lateral plane of normal hearing and no significant difference in the other panes of individual with normal hearing. However, no significant difference was found between all the planes of individual with severe to profound hearing loss .There are significant difference in between group 1 and group 2 for VOR gain for right horizontal canal and left horizontal canal whereas no

significant difference was showed in right posterior canal, left anterior canal, right anterior canal and left posterior canal.

There was association between right posterior plane of vHIT and right cVEMP whereas no association found between cVEMP, oVEMP and other planes of vHIT. There are association between left cVEMP and left lateral plane of vHIT, left cVEMP and left posterior plane of cVEMP and left oVEMP and left anterior plane of vHIT. However, there was no association was found between other test of left ear.

Chapter-5

DISCUSSION

Cervical vestibular evoked myogenic potential

cVEMP was present in 100% in both right and left ear of individual with normal hearing whereas 90% and 75% in right and left ear of individual with severe to profound hearing loss respectively.

The presence of cVEMP in the present study is more compared to the earlier studies. Singh, Gupta, & Kumar, (2012) reported a presence of cVEMP in 87% children of age range 4-12 years with severe to profound hearing loss. Shinjo, Jin, & Kaga, (2007) revealed presence of cVEMP in 75% of the subjects with severe to profound hearing loss. Bansal, Sahni, & Sinha, (2013) reported presence of cVEMP in 98% of individual with sever to profound hearing loss.

Zhou et al., (2009) reported abnormal cVEMP in 21 of 23 children (91%) with sensorineural hearing loss. Zhou et al., (2009) also found significant difference in amplitudes between children with sensorineural hearing loss and normal hearing. Amplitude was lower in children with sensorineural hearing loss compared to children with normal hearing. Also, Ochi & Ohashi, (2001)showed the prevalence of cVEMP in 66.7% of total ears in individuals with sensorineural hearing loss. Shinjo et al., (2007) reported presence of cVEMP in 50% of individual with hearing loss, asymmetrical responses in 30% of the individuals with sensorineural hearing loss, whereas 20% of individual with severe sensorineural hearing loss had absence of response bilaterally. Similar findings were reported by Tribukait, Brantberg, & Bergenius, (2004), Tribukait et al.(2004) reported normal cVEMP responses in 58% of individual bilaterally , 17% individual with asymmetric response and 25%

individual had no VEMP response. Shall & Shall, (2009) reported to have absence VEMP in 22 children of 33 children with profound hearing loss.

The difference in prevalence rate of cVEMP in different studies in sensorineural hearing loss could be due to the difference in population tested. Earlier studies have reported the prevalence in children whereas; the present study bilateral severe to profound sensorineural hearing loss individuals have participated. Also, the etiological factors for the sensorineural hearing loss population tested in these studies were different. In present study, significant difference was found in the amplitude of cVEMP responses.

There was no significant difference found for latencies of right ear whereas significant difference was showed in p1-n1 amplitude complex of right ear of both the groups. However, no significant difference found in the latency of p1 and amplitude complex of p1-n1 of left ear but showed significant difference in latency of n1 of left ear of both the groups. There was no significant difference was found between the two ears in individual with severe to profound hearing loss. However, when the data was combined from two ears, the statistical analysis showed no significant difference between the latencies of p1 peak and n1 peak of cVEMP between the two groups. However, significant difference was found between the p1-n1 amplitude complexes between both the groups in which smaller amplitude was found for individual with severe to profound hearing loss.

Xu et al. (2016) reported that cVEMP was present in 44.4% of individual with profound sensorineural hearing loss and decreased amplitude in cVEMP response in the individuals with sensorineural hearing loss than healthy individuals. Smaller amplitude was found in individual with hearing impaired group compared to normal hearing group. This suggests that there could be abnormality in vestibular function

due to similarities in both morphological and physiological between the cochlear and vestibular structures and functions (Singh et al, 2012, Zhou et al., 2009).

Ocular vestibular evoked myogenic potential

In the present study, oVEMP was present in 100% in both right and left ear of individual with normal hearing, whereas 55% and 60% in right and left ear of individual with severe to profound hearing loss respectively. There was no significant difference for latencies of n1, p1, n2 and amplitude complex of p1-n1 and p1-n2 of right ear in group 1 and group 2. However, significant difference was found between the amplitude complex of n1p1 and p1n2 of both the groups and *found no significant difference between latencies of n1, p1 and n2 in left ear of group1 and group 2 .Combined data of both the ears were analyzed and found no significant difference between the latencies of n1, p1 and n2 of both the groups whereas significant difference was found for the amplitude complex of p1-n1 and p1-n2 of both the groups.*

Similar finding was reported in literature that suggests more utricle dysfunction in individual with severe to profound hearing loss. Previous studies shown that oVEMP response was present in around 60-66% of the individuals with severe to profound sensorineural hearing loss Bansal et al., (2013) . Kaga, Suzuki, Marsh, & Tanaka,(1981) reported hypoactivity of the vestibulo-ocular reflexes in 12 out of 22 children (55%) with severe to profound sensorineural hearing loss based on damped rotation test. Shinjo et al.,(2007) assessed vestibular function using the damped rotation and caloric tests in 20 children with severe sensorineural hearing loss and reported that abnormalities were found in 85% of these children with caloric testing and in 30% with the rotation test. Jacot et al.,(2009) examined 224 children with profound hearing loss, using the caloric and rotation tests. They showed that

50% of the children tested have unilateral or bilateral vestibular dysfunction. Xu et al., (2016) reported to have 38.9% of response rate from oVEMP in individual with PSHL and significantly less amplitude in oVEMP response in individual with profound hearing loss compare to healthy individuals. Niu et al., (2015) reported to have affected oVEMP in 54.8% in individual with sudden sensorineural hearing loss.

Anatomically and physiologically the two parts of the inner ear viz: cochlea and the vestibular organs (semicircular canals and the otolith organs) are closely related to each other (Tribukait et al. 2014). It has also been reported that there are similarities in the vestibular hair cells and cochlear hair cells and the blood supply to both the systems (Starr et al., 2003).The cochlea and the vestibular organs share the same membranous labyrinth of the inner ear and hence the abnormality or the dysfunction of one part may lead to dysfunction of the other part too. In the present study, oVEMP responses are more absent in individual with severe to profound hearing loss than cVEMP that suggest the more utricular dysfunction associated with cochlear pathology than saccular function in individual with severe to profound hearing loss. Tribukait et al.,(2004) reported that cochlea is more closely linked to the utricle than the any other sensory receptors of the inner ear.

It can be hypothesized that the overt manifestation as well as progression of the auditory deficits would be earlier and greater than that of the vestibular symptoms; this is expected to therefore provide more opportunities for compensation to occur for the vestibular symptoms. This is one of the reason why most of the individuals of severe to profound sensorineural hearing loss will not report of any kind of vestibular symptoms. Therefore, it may lead to vestibular dysfunction in individual with severe to profound hearing loss.

Video head impulse test (vHIT):

In vHIT, it was found that mean VOR gain values for right and left horizontal canals, right anterior and left posterior canal for individual with hearing impaired is lesser than the individual with normal hearing.

Thus, it can be interpreted from the present study that horizontal canal of both ears are more affected in individual with severe to profound hearing loss than other canals of both the side. Caloric test and ENG was done previously to assess the functioning of horizontal canal. Magliulo et al., (2015) has found abnormal vHIT in individual with Usher syndrome who had established hearing loss and found that 53.3% had significant superior semicircular canal (SSC) deficit, 33.3% individual with ushers syndrome confirmed with horizontal SCC deficits and posterior SCC deficits was presented with 40% of individual with usher syndrome. These results indicated SCC's damage in individual with Ushers syndrome. Lin et al., (2015) reported to have abnormal vHIT that examined horizontal SCC VOR gain in 38.5% of idiopathic sudden hearing loss. Jutila, Aalto and Hirvonen (2013) measured horizontal VOR gain in children with profound hearing loss was 0.77 ± 0.26. In different pathologies had also shown the lesser VOR gain for horizontal canal which shows dysfunction of horizontal SCC. Different studies have been reported in literature to find the function of SCC's in different pathologies.

Martinez-Lopez et al. (2015) reported that vHIT responses are more affected in LARP in the individual with Meniere's disease. The authors concluded that the vHIT can be a useful tool for the diagnosis of semicircular canal dysfunction in individuals with Meniere's disease. Blödow, Pannasch, & Walther (2013) recorded VOR gain of horizontal semicircular canal in 52 individuals with vestibular neuritis using vHIT. Authors found that VOR gain was abnormal in 94.2% of individuals with vestibular neuritis. Chen et al. (2012) reported 7% of individual with beningn

paroxymal positional vertigo had abnormal vHIT, 24% individual with beningn paroxymal positional vertigo had abnormal head shaking test whereas caloric test showed abnormality in 71% of individual with beningn paroxymal positional vertigo. Authors concluded that low frequency of semicircular canal frequncy tests are sensitve to find BPPV and vHIT cannot be used to evaluate semicircular function in BPPV.

Association between of cVEMP, oVEMP and vHIT:

There was association between right posterior plane of vHIT and right cVEMP whereas no association found between cVEMP, oVEMP and different planes of vHIT. There are association between left cVEMP and left lateral plane of vHIT, left cVEMP and left posterior plane of cVEMP and left oVEMP and left anterior plane of vHIT. However, there was no association was found between other test of left ear.

The research papers in vHIT have just started to appear in the literature and there are only few stuudies which have tried to correlate the vHIT test results with cVEMP and oVEMP test results in individuals with various vestibular disorders. Walther and Blödow, (2013) tested cVEMP, oVEMP and vHIT and found no association between all these tests in a group of individuals diagnosed with vestibular neuritis. Magliulo et al. (2015) also reported no association between the cVEMP, oVEMP and vHIT test in a group of individuals with vestibular neuritis. Oh et al. (2015) reported no correlation between cVEMP, oVEMP and vHIT test findings in a group of individuals with vestibular neuritis.

Lack of associations between cVEMP, oVEMP and different planes of vHIT due to the fact that cVEMP assess the function of saccule, oVEMP assess the function of utricle and vHIT assesses the function of all 6 SCC's. Also, the stimulus used for vHIT is providing head jerks to stimulate all 6 SCC's of different planes which is

more natural way to stimulate the SCC's whereas for cVEMP and oVEMP high intensity acoustic stimulation is used to stimulate saccule and utricle and are more simulated condition.

Chapter 6
SUMMARY AND CONCLUSIONS

The vestibular system is broadly categorized into both peripheral and central system. The peripheral system is bilaterally composed of three semicircular canals (posterior, superior, lateral) and the otolithic organs (saccule and utricle). The semicircular canals detect rotational head movement while the utricle and saccule respond to linear acceleration and gravity, respectively. These vestibular organs are in a state of symmetrically tonic activity, that when excited stimulate the central vestibular system. This information, along with proprioceptive and ocular input, is processed by the central vestibular pathways (e.g. vestibular nuclei) and maintains our sense of balance and position.

Anatomical, histological and physiologic similarities between the cochlear and vestibular end organs explain the relation between hearing loss and vestibular disturbs. As both systems are related, in patients with hearing loss it is important to study the complete balance in order to diagnose and prevent a worse vestibular problem. Since vHIT assesses the SCC's, cVEMP assesses the saccule and oVEMP assesses the utricle, the administration of three tests together will complete the picture of the yestibular system in individuals with severe to profound hearing loss. Hence the present study was aimed to objectively assess the functioning of otoliths (saccule and utricle) and three semicircular canal in individual with severe to profound sensorineural hearing loss using cVEMP, oVEMP and vHIT respectively. Therefore, objective of present study were:

- To find out the functioning of utricle, saccule and semicircular canal in individual with severe to profound sensorineural hearing loss using cervical VEMP, ocular VEMP and vHIT respectively.

- To find out a correlation between cervical VEMP, ocular VEMP and vHIT test in individual with severe to profound sensorineural hearing loss.

To achieve the aim of present study, two groups were taken. Group-I consisted of 20 adult participants (40 ears) having severe to profound hearing loss ranging in age from 15-40 years. Group-II was consists of 20 adult participants (40 ears) in the age range from 15-40 years with normal hearing sensitivity. All the participants underwent a detailed case history, pure tone audiometry, immitance and reflexometry, cVEMP, oVEMP and vHIT tests.

The waveform of cVEMP, oVEMP response and VOR gain of vHIT were obtained from both the groups and it was analyzed for cVEMP parameters of latency p13, n23 and amplitude complex of p13-n23 complex. Similarly for oVEMP parameters of latency of n1,p1 and n2 and amplitude complex of n1-p1 and p1-n2 were analyzed. From the data the mean and standard deviation were calculated and the following statistical analysis was done.

- Normality was checked and found non- normality distribution of data, therefore non- parametric statistical tests was carried out.
- To compare the group 1 and group 2, Mann Whitney U test were carried out for cVEMP, oVEMP and vHIT measures.
- Wilcoxon signed rank test was done to find the relation between two groups.
- Chi square test was done to find the association between cVEMP, oVEMP and vHIT was carried out.

The results obtained from the above statistical measures are as follows:

Cervical vestibular evoked myogenic potential (cVEMP)

- cVEMP was present in 100% in both right and left ear of individual with normal hearing whereas 90% and 75% in right and left ear of individual with severe to profound hearing loss respectively.
- There was no significant difference found for latencies of right ear whereas significant difference was showed in p1-n1 amplitude complex of right ear of both the groups.
- No significant difference found in the latency of p1 and amplitude complex of p1-n1 of left ear but showed significant difference in latency of n1 of left ear of both the groups.
- There was no significant difference between the two ears in individual with severe to profound hearing loss.
- Therefore, combined data of both the ears were taken and found that no significant difference between the latencies of both the groups.
- Significant difference was found between the p1-n1 amplitude complexes of both the group in which smaller amplitude was found for individual with severe to profound hearing loss.

Ocular vestibular evoked myogenic potential (oVEMP)

- oVEMP was present in 100% in both right and left ear of individual with normal hearing whereas 55% and 60% in right and left ear of individual with severe to profound hearing loss respectively.
- There was no significant difference was found between for latencies of n1, p1, n2 and amplitude complex of p1-n1 and p1-n2 of right ear in group 1 and group 2.

- However, significant difference was found between the amplitude complex of n1p1 and p1n2 of both the groups and found no significant difference between latencies of n1, p1 and n2 in left ear of group1 and group 2.
- Combined data of both the ears were analyzed and found no significant difference between the latencies of n1, p1 and n2 of both the groups whereas significant difference was found for the amplitude complex of p1-n1 and p1-n2 of both the groups.

Video head impulse test (vHIT):

- Mean VOR gain values for right and left horizontal canals, right anterior and left posterior canal for individual with hearing impaired is lesser than the individual with normal hearing.
- Mean VOR gain for right posterior and left anterior canal are similar for both the groups.
- Also, there was significant difference found in left and right lateral plane of normal hearing whereas no significant difference was found between all the planes of individual with severe to profound hearing loss and individual with normal hearing.
- There are significant difference in between group 1 and group 2 for VOR gain for right horizontal canal and left horizontal canal.
- No significant difference was showed in right posterior canal, left anterior canal, right anterior canal and left posterior canal.

Association between of cVEMP, oVEMP and vHIT:

- There was association between right posterior plane of vHIT and right cVEMP
- No association found between cVEMP, oVEMP and different planes of vHIT of right ear.

- There are association between left cVEMP and left lateral plane of vHIT, left cVEMP and left posterior plane of cVEMP and left oVEMP and left anterior plane of vHIT.
- There was no association was found between other plane of semicircular canal with the oVEMP and cVEMP response of left ear.

Conclusions

cVEMP, oVEMP and vHIT provides information of peripheral structure of vestibular system , i.e., otolith organs and all six semicircular canals, hence these tests can be utilised to assess various vestibular pathology. Findings of the present study suggest a high prevalence of and cVEMP and vHIT response compared to the oVEMP in individuals with severe to profound hearing loss, that suggestive of more utricular dysfunction is linked with cochlear loss in individual with severe to profound hearing loss compared to saccule and semi circular canals. Previous studies also reported to have more uticular dysfunction in sensorineural hearing loss than saccule and semicircular canals. There is no association between cVEMP, oVEMP and vHIT response. This suggests that all these tests assess function of different structure of peripheral vestibular system which is independent to each other. To conclude, abnormality was seen for both otolith organs (saccule and utricle) and semi circular canals in individual with severe to profound hearing loss, and thus, along with other audiological testing, vestibular testing should also be carried out for these individuals with severe to profound sensorineural hearing loss.

Implications of the study:

1. Based on the results obtained from various test findings, the present study can be utilised to understand the various mechanisms involving the vestibular dysfunction in individuals with severe to profound sensorineural hearing loss.
2. Outcome of this study could lead to development of objective diagnostic tests as well as techniques to monitor the effectiveness of vestibular intervention in the severe to profound sensorineural hearing loss.

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