VESTIBULAR PROFILE IN INDIVIDUALS WITH UNILATERAL SENSORINEURAL HEARING LOSS

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Register No. 11AUD001

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

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Dedicated To

God on Earth

(Maa & Papa)

Certificate

This is to certify that this dissertation entitled **"Vestibular Profile in Individuals with Unilateral Sensorineural Hearing Loss"** is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student with Registration No. 11AUD001. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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This is to certify that this dissertation entitled **"Vestibular Profile in Individuals with Unilateral Sensorineural Hearing Loss"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in other University for the award of any other Diploma or Degree.

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Declaration

This dissertation entitled **"Vestibular Profile in Individuals with Unilateral Sensorineural Hearing Loss"** is the result of my own study under the guidance of Mr Sujeet Kumar Sinha, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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Chapter - 1

Introduction

Unilateral sensorineural hearing loss can affect individuals at any period of their life span, can remain static and/or can be progressive, and can vary in severity ranges from mild to profound. Most of the subjects have an idiopathic etiology. For the diagnosis of idiopathic unilateral sensorineural hearing loss, certain etiological factors such as neoplasms, stroke, demyelinating and autoimmune diseases, infection, perilymphatic fistula, and Meniere's disease, need to be excluded. However, there is a small group of subjects who stays with unilateral hearing impairment, sometimes involves vestibular system also (Voelker & Chole, 2010). Anatomical proximity of the cochlea and the vestibular system and chances of dent caused by the same pathogenic factor implies that sensorineural hearing loss may be coexist with vertigo and dizziness. Hence a minor group of subjects with unilateral sensorineural hearing loss may have vestibular symptoms (Voelker & Chole, 2010).

Magnetic resonance studies have revealed morphological changes in both the cochlea as well as the vestibular system, and these morphological changes in cochlear as well as vestibular system are similar in individuals with unilateral sensorineural hearing loss (Cadoni et. al. 2006). The morphological changes in inner ear of subjects with unilateral sensorineural hearing loss include atrophy of the organ of the corti, loss of cochlear neurons, labyrinthine fibrosis, formation of new bone and degeneration of the spiral ligament, vascular stria, hairy cells, dendrites and apical spiral ganglion cells have been also reported in temporal bone studies (Koc & Sanisoglu, 2003).

Balance is dependent upon integration of signals from the vestibular, visual and the somatosensory systems to generate the motor responses that maintain upright position and adjust to destabilising forces. The vestibular system consists of the semicircular canals and the otolith organs. The assessment of the otolith organs in past has been a major problem. Recently the vestibular evoked myogenic potentials have emerged as a tool to assess the otolith organs. Most of the research efforts have been directed toward VEMPs that are recorded from the cervical (i.e., cVEMP) and infraorbital locations (i.e., oVEMP).

Cervical VEMP is a short latency biphasic potential that represents the response of sacculocollic pathway to loud stimulation. Cervical VEMP testing provide a useful, non-invasive procedure for assessment of sacular function and the functional integrity of the inferior vestibular nerve (Akin, Murnane, & Proffitt, 2003; Al- Abdulhadi, Zeitouni, Al-Sebeih, & Katsarkas, 2002; Chen, Young, & Wu, 2000; Clarke, Schonfeld, & Helling, 2003; Colebatch, Halmagyi, & Skuse, 1994; Ferber-Viart, Duclaux, Colleaux, & Dubreuil, 1997; Li, Houlden, & Tomlinson, 1999; McCue & Guinan, 1995; Ochi, Ohashi, & Nishino, 2001; Welgampola & Colebatch, 2001).

cVEMP has been utilized for the diagnosis of various disorders such as Meniere's disease (Murofushi, Shimuzu, Takegoshi, & Cheng 2001; Iwasaki, Takai, Ito, & Murofushi, 2005), acoustic neuromas (Murofishi, Matsuzaki, & Mizuno, 1998; Murofushi et al 2001), (Streubal, Cremer, Carey, Weg, & Minor, 2001), superior canal dehiscence syndrome (Brantberg, Bergenius, & Tribukait, 1999), vestibular neuritis (Ochi, Ohasi, & Watanabe,2003), vertigo (Yang, Kim, Lee, & Lee, 2008), auditory neuropathy/ audiovestibular neuropathy (Kumar, Sinha, Singh, Bharti, & Barman, 2007) and in other disorders such as cerebellopontine angle tumor (Iwasaki et al 2005). Clinically, the test is very easy to administer and it's available with most of the instruments which having facility to record other evoked potentials.

Ocular Vestibular Evoked Myogenic Potential (o-VEMP) is a short latency tri-phasic potential that represents the response of otolith ocular pathway to loud stimulation. The oVEMP is larger in the eye contralateral to the stimulus (Todd et al., 2007). When recorded infraorbitally, it amplifies on upgaze, possibly arising from the inferior oblique muscle (Rosengren et al., 2005).

oVEMP testing has recently been developed as a new method for assessing the integrity of the utricle and innervating nerves (Rosengren, Todd, & Colebatch, 2005; Chihara, Iwasaki, Ushio, & Murofushi, 2007; Todd, Rosengren, & Colebatch, 2007). The recently developed o-VEMP test has progressively gained popularity in investigating vestibular disorders, such as vestibular neuritis (Lin & Young, 2011), Meniere's disease (Huang, Wang, & Young 2011), and vestibular schwannoma (Ushio, Iwasaki, Murofushi, Sugasawa, Chihara & Fujimoto, 2009).

Caloric test is a part of the ENG (Electronystagmography) test battery & it assesses the horizontal semicircular canal and its innervating structure, comprising of a direct excitatory projection from the horizontal semicircular canal to the medial vestibular nucleus, then to the ipsilateral medial rectus sub nucleus through the ascending tract of Deiters (Straka & Dieringer, 2004). Caloric test assess the activity of the horizontal semicircular canal. It is known to reliably and accurately differentiate between normal vestibular output and abnormally reduced or increased output. (Baloh, Sills, Solingen, & Honrubia, 1977; Zapala, Olsholt, & Lundy, 2008).

Combination of cVEMP, oVEMP and caloric test will give information about integrity of saccule, utricle and horizontal semicircular canal and its neural connections.

Need for the Study:

1. Previous studies have revealed difficulty in balancing among the individuals with unilateral sensorineural hearing loss (Schuknecht, 1993; Voelker & Chole, 2010). This suggests the importance of an objective test to assess the vestibular system in such individuals.
2. Studies have reported that in subjects with unilateral sensorineural hearing loss inferior vestibular nerve is more likely to be involved than the superior vestibular nerve (Jung, Yun, & Suh, 2012). The density of vestibular hair cells seemed to decrease on the saccular macula and the posterior semicircular canal crista (Inagaki, Cureoglu, Morita, Terao, Sato, Suzuki, & Paparella, 2012). This suggests the importance of an objective test to assess the vestibular system in such individuals.
3. Equivocal findings are available in the literature regarding the effect of unilateral sensorineural hearing loss on caloric test (Melagrana, Tarantino, Agostino & Taborelli, 1998; Pajor, Gryczynski, Lukomski & Jozefowicz-Korczynska, 2002). Hence, further this needs to be explored.
4. Caloric test assesses the horizontal semicircular function, whereas, cVEMP assess sacculocollic pathway. The sacculocollic pathway can also be affected in individuals with unilateral sensorineural hearing loss. Thus there is a need to evaluate the integrity of sacculocollic pathway and hence there is a need to conduct the cervical vestibular evoked myogenic potentials test in individuals with unilateral SNHL.
5. oVEMP is the new kind of variation of VEMP responses. Combining oVEMP and cVEMP provide complementary information about saccular and utricular otolithic function. There is dearth of information regarding oVEMP recording

in the clinical population. So there is need to study the oVEMP in individuals with unilateral SNHL.

Aim of the Study

To compare cVEMPs, oVEMPs and caloric test results in individuals with unilateral sensorineural hearing loss.

Objectives of the Study

1. To find out the effect of unilateral sensorineural hearing loss on cervical VEMP, ocular VEMP and caloric tests.
2. Correlation between cervical VEMP, ocular VEMP and Caloric test in the unilateral sensorineural hearing loss.
3. Correlation between the cervical VEMP, ocular VEMP and Caloric test findings with the duration of unilateral sensorineural hearing loss.
4. Correlation between the cervical VEMP, ocular VEMP and Caloric test with the degree of hearing loss in individuals with unilateral sensorineural hearing loss. To correlate the cervical VEMP ocular VEMP and Caloric test findings with the vestibular symptoms (if they exhibit any) in individuals with unilateral sensorineural hearing loss.

Chapter - 2
Review of Literature

Sensorineural hearing impairment can be congenital or acquired and it can be unilateral or bilateral in nature. Unilateral sensorineural hearing loss (USNHL) can occur in individuals at any period of their life span. It can be vary in its severity it may remains static or it can be progressive in nature, and also its severity can ranges from mild to profound. Most of the individuals have idiopathic etiology, there are also known pathologies of unilateral SNHL which has to be debarred while diagnosing unilateral sensorineural hearing loss including neoplasms, stroke, demyelinating and autoimmune diseases, infection, perilymphatic fistula, and Meniere's disease. The recovery pattern for majority of individuals with idiopathic sudden SNHL will vary some may recover complete or partial hearing. However, unilateral hearing impairment will remains in small group of subjects. To test the severity of impairment and structures involved clinicians require a test battery which includes detailed audiological and vestibular testing. Vestibular test battery includes electronystagmography, cervical vestibular evoked myogenic potential and ocular vestibular evoked myogenic potential.

Caloric test is a part of electronystagmography test and is a diagnostic test to record the corneoretinal potential through involuntary movements of the eyes caused by the condition known as nystagmus. The nystagmus occurs because of the anatomical connection between the vestibular system and ocular system (vestibule-ocular reflex system). Since the eye movements result in changes in the electrical field around the eyes are recorded using ENG as nystagmus. ENG is widely accepted and most commonly used to assess the individuals with complaint of dizziness.

The caloric test, which is a subtest of ENG testing, evaluates the rotational VOR system, comprising of a direct excitatory projection from the horizontal semicircular canal to the medial vestibular nucleus, then to the ipsilateral medial rectus sub nucleus through the ascending tract of Deiters. Another direct excitatory pathway projects to the contralateral abducens nucleus. The latter contains both motor neurons to the lateral rectus muscle and interneurons that travels via the medial longitudinal fasciculus to medial rectus motor neurons. The anatomical pathway involved in caloric test is shown in figure 2.1.

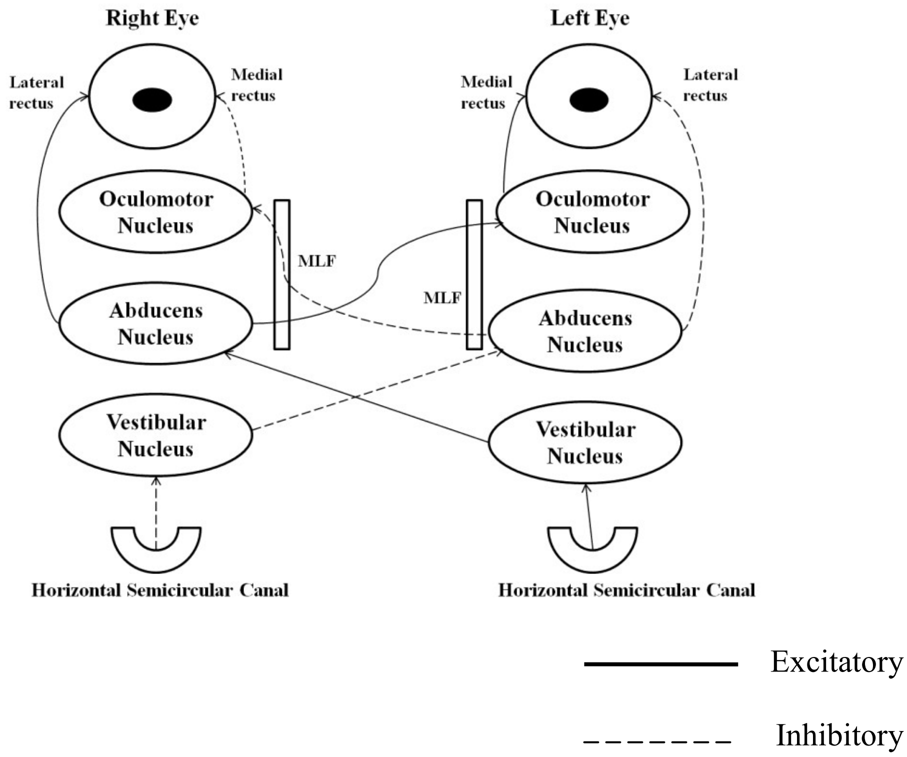


Figure 2.1: Vestibulo – ocular reflex pathway

ENG basically evaluates the functioning of vestibule ocular reflex system, but there are other reflexes also like the vestibule spinal reflex and the vestibule colic reflex which are very important for the maintenance of the balance but are not tested by ENG. Other vestibular function tests are also important thus, ENG is just a part of battery of test that is important to evaluate vestibular function.

Through air-conduction stimuli, vestibular evoked myogenic potential (VEMP) has been successfully recorded in humans from ipsilateral neck muscles and contralateral extraocular muscles. The earlier one is called cervical VEMP (cVEMP), which is used to assess the ipsilateral vestibulo-collic reflex (Kirtane, 2009), while the later one is called ocular VEMP (oVEMP). It is applied to evaluate the crossed vestibulo-ocular reflex (Kirtane, 2009). Like the cVEMP test, the newly developed oVEMP test has gained popularity to examine vestibular disorders, e.g. vestibular neuritis, Meniere's disease (MD), and vestibular schwannoma.

The neurophysiological studies, previous literature and clinical research data reports that the cervical vestibular evoked myogenic potentials are carried through the pathway which consists of the structure like macula of saccule, inferior vestibular nerve, the medial vestibular nucleus, the medial vestibule spinal tract, the motor neurons of the ipsilateral sternocleidomastoid muscle (SCM) (Halmagyi & Curthoys, 1999). The anatomical pathway involved in cVEMP is shown in figure 2.2.

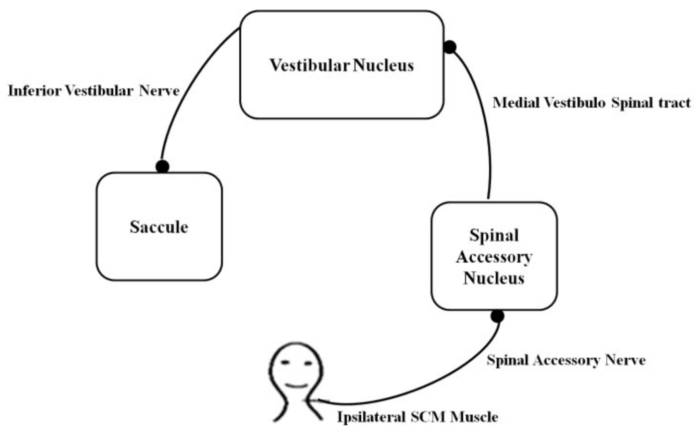


Figure 2.2: Neural pathway for cVEMP.

oVEMP is a new variation of VEMP assesses the functioning of crosses otolith- ocular pathway. The oVEMP test assesses the translational VOR system by activating the otolithic maculae, and then travels through the utricular branch of the superior vestibular nerve and a small branch from the hook portion of the saccule, which ascends via the vestibular nuclei to the opposite extraocular muscles. The neuronal pathway for oVEMPs via the vestibule – ocular reflex include activation of the vestibular nerve and vestibular nucleus, medial longitudinal fasciculus (MLF), oculomotor nuclei, ocular nerves and to the contralateral nerves and to the contralateral extraocular muscles (Rosengren, Welgampola, & Colebatch, 2010). The anatomical pathway involved in oVEMP is shown in figure 2.3.

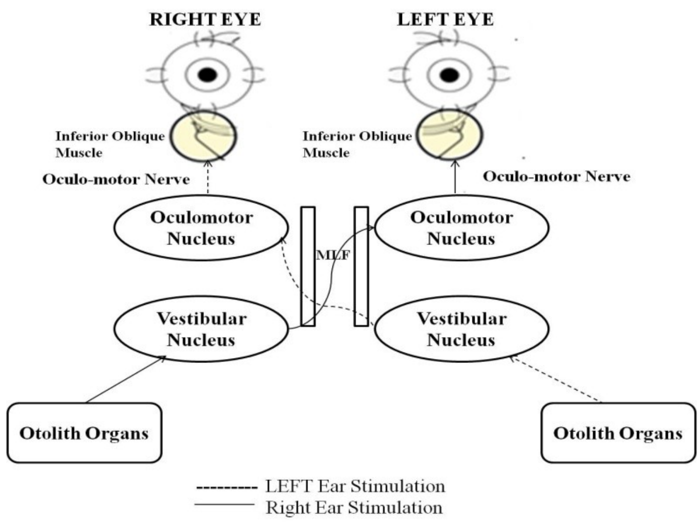


Figure 2.3: Neural pathway for oVEMPs.

Anatomy of Inner ear

The inner ear consists of series of interconnecting canals and is located in the petrous part of the temporal bone. These series of interconnecting canals are collectively called as labyrinth, because of the complexity of its shape. Labyrinth is divided into two parts first is bony labyrinth which consists of semi-circular canals, vestibular part and cochlear part. These are cavities within the bone, lined by periosteum and containing a clear fluid, the perilymph. Second is the membranous labyrinth which consists of semi-circular ducts, otolith organs, and cochlear duct. It is much narrower and is filled with endolymph, a fluid of unique composition.

Vestibular system lies in close proximity to the cochlea. The cochlear duct within the osseous cochlea, parts form a closed system of channels which communicate freely with one another. The semicircular ducts open into the utricle and this opens into the saccule via the ductus utriculosaccularis, which also joins the ductus endolymphaticus. The saccule opens into the cochlear duct through the ductus reunieus. All of these structures share the common fluid known as endolymph.

The main blood supply to the vestibular end organs and the cochlea is through the common internal auditory artery, which usually arises from the anterior cerebellar artery, superior cerebellar artery, or basilar artery. Shortly after entering the inner ear, the labyrinthine artery divides into two branches known as the anterior vestibular artery and the common cochlear artery. The nerve supply to the vestibular system and the cochlea is through the vestibulocochlear nerve, which bifurcates into vesibular and cochlear nerve once it comes out of the internal auditory meatus.

As both the vestibular and cochlear organ are in close proximity to each other, there is a high possibility of any disease, pathology or lesion affects the functioning of the neighbor structures. So any damage to one structure may lead to changes in other structure in terms of anatomical and physiological changes.

Jang et. al. (2012), studied the temporal bone computed tomography to determine the relationship between bony cochlear nerve canal size and unilateral sensorineural hearing loss. They found positive correlation between the length and width of bony cochlear nerve canal in the affected inner ears of patients with congenital unilateral sensorineural hearing loss, but not in normal hearing inner ears. Presently, bony cochlear nerve canal length and width in the affected inner ears of congenital unilateral sensorineural hearing loss were significantly smaller than those of normal hearing inner ears, there were no significant differences between the unaffected cochleas in patients with unilateral sensorineural hearing loss and normal controls without SNHL. On the other hand, the length and width of bony cochlear nerve canal in the affected inner ears in unilateral sensorineural hearing loss patients were significantly smaller than control and contralateral inner ears in unilateral sensorineural hearing loss patients. Bony cochlear nerve canal narrowing may be associated with hearing loss in congenital unilateral sensorineural hearing loss patients.

Vestibular problems associated with idiopathic sudden sensorineural hearing loss (ISSHL) could results from ultrastructural changes in hair cells and their synapses. Khetrapal, (1991) investigated the cause of vertigo in sudden unilateral sensorineural hearing loss. An attempt was made to find a morphologic correlate of vertigo associated with idiopathic sudden sensori-neural hearing loss. Hair cell densities of the three cristae and both maculae, as well as vestibular ganglion cell (neuronal) count estimation, were done in nine ears that had documented histories of ISSHL.

Proximity of the anatomical structures of the inner ear and the chances of harm caused by the same pathogenic factor to the inner ear structure which causes vertigo and dizziness in individuals with unilateral sensorineural hearing loss studied by Pajor et.al (2002). Pajor et.al (2002) evaluated individuals with unilateral sensorineural hearing loss using electronystagmography in 126 subjects to see the occurrence of dysfunction of vestibular system and to make analysis based on the severity and type of the hearing loss exists in the individuals. A 50% of subjects reported presence of vertigo and 30% of them reported having dizziness. 72% of the individuals showed abnormal electronystagmography findings. Pajor et.al (2002) found lack of correspondence between severity and type of hearing impairment and vestibular damage.

Rambold et.al., (2005), studied differential vestibular dysfunction in sudden unilateral hearing loss, Auditory and vestibular function was examined in 29 patients to identify characteristic vestibulocochlear lesion patterns. In 45%, a vestibular lesion was found, of which 53% had a combined impairment of the cochlea and the ipsilateral posterior semicircular canal, possibly reflecting vascular disease in the common cochlear artery.

ENG, cVEMP and oVEMP responses in different clinical population

a. Meniere's disease

Caloric test has been found a strong tool to diagnose vestibular problems in individuals with Meniere's disease. There are studies which suggest that caloric responses are hypofunctional in Meniere's disease. Bergman and Stahle (1967) studied electronystagmography in 300 individuals with Meniere's disease. The caloric testing revealed a normal response in 49 individuals (16%) and an abnormal response in 251 (84%) among 251 individuals.

In individuals with Meniere's disease, equivocal findings in caloric testing have been reported. Thomas and Harrison (1971) studied caloric test findings in 610 cases with Meniere's disease. Result showed absent caloric responses in 41 subjects (7.3%), hyperactive caloric responses in 4 subjects (0.7%).

There was no correlation found between the mean hearing loss and the magnitude of caloric response reduction on the day of investigation. Hulshof and Baarsma (1981) conducted vestibular investigation in 151 individuals with unilateral Meniere's disease in the interval between vertigo attacks, and the results were compared with those obtained in the control group. 111 individuals (73.5%) showed reduced excitability unilaterally. The difference in excitability was found to increase significantly with increasing duration of the complaints but not with increase in hearing loss.

Various studies have reported abnormal cVEMP result in individuals with Meniere's disease. Taylor et.al, (2011) reported abnormality of cVEMP in unilateral Meniere's disease in 60 subjects and the prevalence of unilateral VEMP abnormalities was 50%. Murofushi and Kaga (2009) studied cVEMPs responses on 81 individuals with Meniere's disease study done by. They found that out of all the 81 subjects cVEMPs was abnormal in 39 (48%) on the poorer side, decreased cVEMPs amplitude in 8 individuals and normal cVEMPs responses showed by 34 subjects. Thus, abnormal cVEMPs in individuals with Meniere's disease showed overall incidence of 58%.

Baier and Dieterich (2009) reported cVEMP findings in 16 subjects, which showed that 11 (69%) subjects had reduced amplitude and there was no difference in the latencies. cVEMPs response in individuals with Meniere's disease was absent or abnormal or with prolongation in the latency in affected side. The responses of cVEMPs in individuals with Meniere's disease were compared with the subjects with no Meniere's disease (Murofushi, Shimizu, Takegoshi & Cheng, 2001). Authors reported that out of the 43 individuals, 15 had absence of p13 peak and n23 peak on the affected side and decreased responses showed by 7 and normal responses showed by 21.

Individuals with Meniere's disease showed same results regarding latencies of cVEMP responses found by Hong, Yeo, Kim and Cha (2008). Authors studied 29 individuals with unilateral Meniere's disease to see there cVEMP responses. Authors found abnormal cVEMP results in 69% and for these subjects amplitude asymmetry between ears were more. They concluded that cVEMP is most sensitive to test individuals with Meniere's disease.

Stage of Meniere's disease can be correlated with the interaural amplitude difference ratio in cVEMP responses. Young, Huang, and Cheng (2003) reported there is significant relationship between interaural amplitude ration and stage of Meniere's disease for 40 individuals.

The interaural amplitude difference ratio can differentiate the first and other stages of Meniere's disease (Osei-Lah, Ceranic and Luxon, 2008). In individuals with Meniere's disease the cVEMP threshold was reported to be elevated. Rauch, Zhou, Kujawa, Guinan and Herrmann (2004) reported that, in comparison between normal subjects and contralateral ears of unilateral Meniere's subjects, Meniere's ears had statistically elevated cVEMP thresholds. Contralateral ears of Meniere's subjects also showed statistically increased cVEMP thresholds in comparison to normal subjects. They attributed that in Meniere's disease, there are changes in the saccule.

In unilateral Meniere's disease cVEMP threshold was shown to be easily get affected in the affected side. Rauch et al. (2004) studied individuals with unilateral Meniere's disease to see of cVEMP threshold sensitivity in the affected side. In unilateral Meniere's disease results showed that cVEMP threshold was more prone to get change. This supports the hypothesis that cVEMP supplies additional information to the results of the vestibular test battery.

In individuals with Meniere's disease normal latencies were found for oVEMP responses. Chiarovano, Zamith, Vidal and Waele (2011) in 26 individuals with Meniere's disease oVEMP were recorded and results showed that oVEMP latencies in the abnormal side were not statistically poles apart from the latencies in contralateral side or those from the normal individuals.

Correlation between ENG, cVEMP and oVEMP

In individuals with Meniere's disease oVEMP responses were repeatedly absent than the cVEMP responses. Chiarovano et al. (2011) in 26 individuals with Meniere's disease oVEMP, caloric and cVEMP test were administered. Out of 26 individuals, 5 showed reduced amplitude and 8 showed absent responses in cVEMP in the affected side.18 subjects showed reduced or absent responses in oVEMP in affected side. Dissociation was found between oVEMP and cVEMP in 50% of the subjects. The caloric results were not in a correlation with of either cVEMP or oVEMP responses on the affected side. Abnormal findings can be seen first in cVEMP than oVEMP or caloric testing in early stages of Meniere's disease,

There is no correlation between air conduction evoked oVEMP and cVEMP responses. Murofushi, Nakahara, Yoshimura and Tsuda (2011) studied 20 individuals with Meniere's disease and recorded oVEMP, caloric and cVEMP responses. Results showed no significant association between oVEMP and cVEMP findings but there was alliance of oVEMP test results with caloric test results in the individuals with Meniere's disease.

In fifty individuals with unilateral Meniere's disease cVEMPs, oVEMPs (for bone conduction stimuli) caloric tests were administered (Huang, Wang and Young, 2012). Results showed that abnormal caloric for 24%, oVEMPs for 44% and for cVEMPs 38% in individual with unilateral Meniere's disease. There was no statistical relation found between any of the two (caloric, cVEMPs and oVEMPs) test results. Site of lesion can be found by the caloric test, cVEMPs and oVEMPs results findings in subjects with unilateral Meniere's disease.

The locations of vestibular dysfunction can be known by combining the test results of the caloric test, oVEMP and cVEMP in the vestibular system. In a patient with unilateral Meniere's disease caloric, oVEMP, and cVEMP test were administerd by Jacobson et al. (2011) and results showed that cVEMP was absent in the disease ear and present in the normal side. oVEMP and caloric responses were normal in both the sides. oVEMP gives information about the different site of the peripheral vestibular system i.e. utricle which is different from the measured by cVEMP (it get stimulated by saccule), and which is similar to the area tested by caloric i.e. the superior vestibular nerve.

b. Vestibular Neuritis

ENG findings in individuals with vestibular neuritis is complete or near complete loss of unilateral caloric responses, it is interesting that individuals with vestibular neuritis may except to recover some function with time (Wennmo & Pyykko, 1982; Corvera & Davalos, 1985). Wennmo and Pyykko (1982) studied electronystagmography in 30 individual's primary diagnosed as having vestibular neuritis. In the caloric test, all 30 individuals showed reduced responses.

Murofushi, Halmagyi, Yavor and Colebatch (1996) reported that 31 of 47 subjects (66%) with vestibular neuritis had cVEMP responses on the affected side but that 16 subjects (34%) had an absence of cVEMP. Murofushi & Kaga (2009) performed a similar study among the 68 patients with vestibular neuritis. Results showed 34 (54%) of the ears with vestibular neuritis had normal cVEMP findings. These results imply that a considerable number of subjects with vestibular neuritis could have deficits of functions of the saccule and/or its afferents. Their results suggested that the vestibular neuritis could be subdivided into the total vestibular neuritis and superior vestibular neuritis.

In vestibular neuritis, there are equivocal findings regarding absence or presence of cVEMP. Murofushi, Shimizu, Takegoshi and Cheng (2001) studied cVEMP in 23 individuals with vestibular neuritis and normal control group. Results showed that cVEMP responses were absent or reduced in 9 (39%) individuals with vestibular neuritis. Individuals with vestibular neuritis did not show latency prolongation. Individuals with vestibular neuritis may have complete damage or no damage to the inferior vestibular nerve.

Interpretation of cVEMP results in vestibular neuritis should be done cautiously in aged patients. Study done by Hong, Yeo, Kim, and Cha (2008) showed that, of the 134 individuals with vestibular neuritis, 49 (36.6%) showed absent cVEMP response when it was compared to the individuals with no pathology. Authors have reported that vestibular neuritis can affect the superior and inferior nerves both or it can only affect the superior vestibular nerve. Therefore, it can be concluded that cVEMP could detect site of lesion in the vestibular system. In this study, 36.6% of individuals with vestibular neuritis were thought to have lesions in the saccule or inferior vestibular nerve.

Chiarovano et al. (2011) studied oVEMP, caloric testing and cVEMP in 12 individuals with vestibular neuritis at the acute stage. Eight out of 12 (66.6%) subjects showed abnormal cVEMP responses and nine out of 12 (75%) subjects showed abnormal cVEMP responses, and nine out of 12 (75%) subjects showed abnormal oVEMP responses. oVEMP and cVEMP latencies of the poorer ear were not statistically different from the latency of the normal ear or the latency from the normal individuals with no vestibular neuritis. In 50% of participants there was disassociation between oVEMP and cVEMP. In acute phase of vestibular neuritis the superior vestibular nerve is most commonly lesioned than the inferior vestibular nerve. Using oVEMP and cVEMP will help us to know whether or not neuritis spared inferior vestibular nerve.

c. Acoustic Neuroma

ENG is a valuable aid in establishing a definitive diagnosis of acoustic neuroma and in evaluating its probable size and extent. Kirtane, Medikeri, Merchant, Desai and Bhanage (1985) studied ENG findings in 30 individuals with acoustic neuroma. Caloric test was administered in 27 patients and results showed abnormal caloric responses on the tumour side, 25 had hypoactive, 2 had absent caloric responses, and 3 patients had normal responses. In the opposite ear 11 subjects had normal responses, 10 had hyperactive and 9 had hypoactive responses.

ENG is helpful in differentiating intracanalicular and extracanalicular acoustic neuroma. Haapaniemi, Laurikainen, Johansson, Rinne and Varpula (2000) recorded ENG in 41 individuals with unilateral acoustic neuroma were diagnosed by MRI. Tumor location was determined by MRI and cases were divided into intracanalicular and extracanalicular ones. The ENG pursuit test was more frequently normal and the caloric side difference was smaller in ears with intracanalicular than extracanalicualar acoustic neuroma.

Caloric test has good sensitivity and poor specificity in identifying cerbello pontine angle tumours. Harder (1998) studied sensitivity and specificity of electronystagmography in patients with CPA tumours. Electronystagmography were recorded in 78 individuals with CPA tumours and 92 individuals with symptoms and signs suggestive of such a lesion but with a negative computerised tomography scan. The author reported the sensitivity of caloric asymmetry was 88% and specificity was 10%.

cVEMP could be useful for the diagnosis of acoustic neuroma. Murofushi, Matsuzaki and Mizuno (1998) reported that out of 21 individuals, surgically and histopathologically confirmed acoustic neuroma, cVEMP was absent on the affected side in 15 individuals (71%) and significantly decreased in amplitude in 2 individuals (9%). Thus, 17 (80%) of the 21 individuals showed abnormal cVEMP. Three individuals had abnormal cVEMP although they had normal caloric responses. Three individuals had abnormal caloric responses although they had normal cVEMP.

At higher intensities of clicks and short tone burst provides the better picture of the functionality of the saccular nerve in individuals with acoustic neuroma. Patko, Vidal, Vibert, Tran and de Waele (2003) recorded cVEMP using click and 500Hz short tone burst in 170 subjects with acoustic neuroma. Thirty six out of 170 individuals (21.2%) had normal responses to clicks and to short tone burst whereas 134/170 (78.8%) had abnormal or no responses, 78/170 (45.9%) had no response to both clicks and short tone burst. In 56 out of 170 patients (39.2%). cVEMP elicited higher intensity of clicks and short tone burst were discordant: short tone burst cVEMP were present in subjects with absent response to clicks. In contrast, short tone burst induced cVEMP were always present in cases of normal responses to clicks. These results indicate that clicks are useful to detect a minor saccular nerve dysfunction. In cases in which there is no response to clicks, short tone burst gives valuable information about a potential residual function of the saccular nerve.

oVEMPs and cVEMPs provide complementary information about involvement of superior and inferior vestibular nerve in subjects with acoustic neuroma. 12 individuals with unilateral auditory neuroma were studied by Chiarovano et al. (2011). They administered oVEMPs, caloric and cVEMPs. Six out of 12 (50%) subjects showed abnormal cVEMPs responses only on the affected side. Nine out of 12 (75%) subjects showed no oVEMPs responses on the affected side. oVEMP and cVEMP latencies in the poorer ear were not statistically different from the latencies of in the better side or from the normal individual with no acoustic neuroma. In 25% participants there was disassociation between oVEMPs and cVEMPs.

Suzuki, Yamada, Inoue, Kashio, Saito, and Nakanishi, (2008) recorded caloric response and cVEMPs in 130 subjects and found that patients with unilateral vestibular schwannoma of 10 to 19 mm or the intermediate type pathologically diagnosed by surgery, p13 and n23 latencies of cVEMPs are significantly prolonged compared to that of the normal opposite ear. Abnormal rates of caloric response and cVEMPs in individuals with tumours arising from the superior vestibular nerve were not significantly different from those in patients with tumours cannot be predicted based on caloric response and cVEMPs and prolonged cVEMPs latencies seem to be not only caused by tumour compression to the brainstem or vestibular spinal tract but also by tumour compression isolated to inferior vestibular nerve.

oVEMPs test results are statistically significant with caloric test results for subjects with acoustic neuroma. Huang, Wang and Young (2012) studied oVEMPs, cVEMPs and caloric test in 16 subjects with unilateral acoustic neuroma. Results showed that, the caloric test showed abnormal results in 10 ears, while the oVEMPs were abnormal for 12 ears and cVEMPs were abnormal for 11 ears. A statistical significance was present between caloric test and oVEMPs test results, but not among caloric test and cVEMPs test results, and among oVEMPs and cVEMPs test results.

Both the caloric test and oVEMPs assess the functioning of superior vestibular nerve, whereas cVEMPs assess the functioning of inferior vestibular nerve. Thus the oVEMPs test combined with the cVEMPs test can determine whether the origin of the acoustic neuroma is superior or inferior vestibular nerve.

d. Noise Induced Hearing loss

A tendency towards decreased caloric responses had been reported in individuals with noise induced hearing loss (NIHL). Shupak, Bar-EL, Podoshin, Spitzer, Gordon and Ben-David (1994) studied the vestibular findings in group of individuals with noise induced hearing loss and individuals with hearing loss. Electronystagmography was carried out in 22 individuals with NIHL and 22 matched controls subjects. The ENG recordings revealed spontaneous horizontal nystagmus in 6 subjects (27%) in the study group.

Prolonged latency of cVEMPs response has been reported in individuals with NIHL. Fakharnia, Sheibanizadeh, Jafari and Hoseini (2009) studied cVEMPs and caloric testing in 30 individuals with NIHL and 30 normal control subjects. Results showed that no significant difference was observed in unilateral weakness between two groups. On the other hand, the difference in mean latencies of p13 in the right ear and left ear was significant between the two groups. However, the difference in n23 latency was significantly only in the right ear. There was no significant difference between groups in p13-n23 amplitude. Authors concluded that in general, abnormal findings in both cVEMPs and caloric test were more common compared to functional symptoms such as vertigo, which may be due to central compensation and the symmetry of the disorder.

Chronic noise exposure leads to damage in the vestibular part, especially the sacculocollic reflex pathway. Wang and Young (2007) studied cVEMPs and caloric responses in 20 individuals with chronic noise induced hearing loss. Caloric and cVEMPs findings revealed abnormal responses in nine (45%) and 10 (50%) patients, respectively. However, when both results were considered together, the abnormal rate reached 70%. The hearing threshold of 4 kHz significantly associated with cVEMPs results but not with caloric responses.

e. Bening Paroxymal Positional Vetigo (BPPV)

Abnormal Electronystagmography are usually seen in individuals with BPPV. Korres, Balatsouras and Ferakidis (2004) studied electronystagmography in 151 subjects with involvement of the posterior canal, 14 with horizontal canal, and 3 with the anterior canal. Seventy two individuals (42.8%) had abnormal findings on the caloric tests.

cVEMPs provides valuable information in diagnosing subjects with BPPV. Akkuzu, Akkuzu and Ozluoglu (2006) studied cVEMPs responses in 25 subjects with BPPV and normal control group. Results showed that 30 affected ears in the 25 BPPV patients revealed prolonged latencies in eight ears decreased amplitude in one ear. The rate of abnormality is significantly greater in individuals with BPPV than in the control group.

cVEMPs responses are abnormal in individuals with BPPV irrespective canal involved. Hong, Park, Yeo and Cha (2008) studied cVEMPs responses in BPPV involving each semicircular canal. 13/53 subjects with BPPV (24.5%) showed abnormal cVEMPs responses in the affected side than the age match control group. Hong, Yeo, Kim and Cha (2008) also studied cVEMPs responses in 62 individuals with BPPV. 16 subjects (25.8%) showed abnormal cVEMPs findings. The amount of prolongation of p13 latency in these subjects with abnormal cVEMPs responses was higher compared with the other two diseases (Vestibular neuritis and Meniere's disease).

In BPPV, cVEMPs help to better define the extent of saccular damage and the patient's prognosis. Longo, Onofri, Pellicciari and Quaranta (2012) measured cVEMPs responses in 23 subjects with BPPV of posterior semicircular canal involvement and normal control group. Results showed that cVEMPs thresholds and latencies were not different between patients and controls. As a group BPPV patients presented significantly higher abnormal cVEMPs compared with controls. Authors reported that degeneration of neural elements and their interaction with otolithic and canalicular receptors may participate in the pathophysiology of BPPV, including an imbalance between the interaction of the upper part of the macula and the posterior semicircular canal. The fact that cVEMPs may be normal, absent or sometimes prolonged confirms that both mechanisms may be true and could occur together.

oVEMPs response in individuals with BPPV has not yet been studied. The recording of oVEMPs will better define the extent of utricular and superior vestibular nerve damage in individuals with BPPV.

f. Superior Canal Dehiscence Syndrome (SCDS)

cVEMPs responses are having low thresholds in individuals with superior canal dehiscence syndrome. Brantberg, Bergenius and Tribukait (1999) studied cVEMPs in 3 subjects with superior canal dehiscence syndrome. Result showed that abnormally large sound induced cVEMPs. Low threshold, especially in the frequency 0.5kHz & 1kHz was found in cVEMPs. Howeve, using skull taps to stimulate saccule, i.e. when the middle ear route was bypassed, the cVEMPs were not enlarged. This gives information about the use of skull tap, which can differentiate abnormal cVEMPs recorded due to dehiscence of bone overlying the labyrinth, because only the latter would produce large sound induced cVEMPs compared to those induced by skull taps.

There are studies which report a good sensitivity and specificity for cVEMPs in the diagnosis of SCDS. Zhous, Gopen and Poe (2007) reported 26 subjects with dehiscence confirmed radiologically. Results showed that 91.4 % sensitivity and 95.8% specificity for cVEMPs. Authors concluded that vestibular evoked myogenic potential is highly sensitive and specific for SCDS, possibly better than high resolution computerized tomography.

Increased amplitude of n10 component in oVEMPs response, low oVEMPs threshold are observed in individuals with SCDS. Rosengren, Halmagyi, Todd and Colebatch (2008) measured oVEMPs responses in 9 subjects with confirmed SCDS and 10 normal control groups. Results revealed that amplitudes of oVEMPs were in outsized than normal and thresholds were much lesser.

g. Auditory neuropathy/ audiovestibular neuropathy

Abnormal vestibular function is observed in individuals with auditory neuropathy. Starr, Picton, Sininger, Hood and Berlin (1996) studied vestibular function in individuals with auditory neuropathy. Results showed that vestibular function was impaired in several patients. Caloric testing of vestibular function elicited normal horizontal nystagmus and vertigo in two patients out of 4 patients tested but was ineffective in evoking these responses in two other patients.

Abnormal caloric and cVEMPs response has been observed in patients with auditory neuropathy. Sheykholeslami, Kaga, Murofushi and Hughes (2000) studied ENG and cVEMPs responses in 3 individuals with auditory neuropathy. The caloric test was abnormal in all 3 subjects. cVEMPs responses were absent in all 3subjects.

Authors conclude that, in patients with isolated auditory neuropathy, the vestibular branch of the VIIIth cranial nerve and its innervated structures may also be affected.

Kumar, Sinha, Bharti, and Barman (2007), described cVEMPs in 10 subjects with auditory neuropathy, they concluded that 80% of the ears with auditory neuropathy showed abnormal cVEMP results giving an indication of high incidence of vestibular involvement in the auditory neuropathy population.

Masuda and Kaga (2011) studied influence of aging on auditory and vestibular functions in three patients with auditory neuropathy. Caloric testing and cVEMPs was measured in 3 subjects with auditory neuropathy. Vestibular function is decreased in auditory neuropathy compared with healthy subjects. Two out of 3 subjects showed a decline in vestibular function with age.

Audiological findings in unilateral sensorineural hearing loss

A retrospective study in 146 patients with unilateral sudden sensorineural hearing loss was done by Chang, Ho and Kuo, (2005). The severity of hearing loss was evaluated with the average hearing level at five frequencies (250, 500, 1000, 2000, and 4000Hz) and they were classified as per the seven pattern classification system (categorization of hearing loss depending on the thresholds at 250 Hz, 1000Hz and 4000Hz in comparison with the other ear). Results showed average hearing loss in the affected side was 77.1 dB (range, 32 to 113 dB).

A prospective study done by Amiridavan et al., (2006), reported that the mean value of hearing loss was ≥65 dB in 65% of patients, and the most common pattern in PTA curves was the flat pattern (70% of cases), TEOAE of 53 patients showed negative or no signal to noise ratio in 22 (41.5%). Twenty-six patients (49%) had positive overall correlations less than 50%, and 5 patients (4.4%) had overall correlations >50%. Twenty out of 52 patients had no reproducible wave in ABR

(38.5%), and waves I, III, and V were absent in 40 (77%), 31 (59.6%) and 21 (40%) patients, respectively. They concluded that ABR has limitations for use in SSNHL and but also no need to go for brain MRI, but may help in determining the site of lesions such as ischemia or neuropathy. Overall correlation (and S/N ratio) in TEOAE is a valuable prognostic factor in SSNHL, hence they recommend performing TEOAE in every patient with SSNHL.

Brainstem auditory evoked potential (BAEP) was administered in 23 patients with sudden sensorineural hearing loss by Habib, Huasain, Omar and AI Drees, (2011). Results showed that in left ear 9 (39.1%) patients were affected, in right ear 13 (56.5%) patients were affected and both in 1 (4.3%). Absolute latency of wave I and wave V were significantly prolonged in affected ear compared to unaffected ears, while inter peak I-V latency was significantly higher in affected ears versus unaffected ears.

Sudden sensorineural hearing loss is usually unilateral and can be associated with tinnitus and vertigo (Schreiber, Agrup, Haskard & Luxon, 2010). Rauch (2008) did a clinical study on subjects with unilateral sudden sensorineural hearing loss and reported that it occurs between 43 years to 53 years of age with equal sex distribution. Vestibular symptoms like of aural fullness, loud tinnitus and mild vertigo are present in 28 to 57% of patients.

ENG, cVEMP and oVEMP findings in unilateral sensorineural hearing loss

Huang et al., (2012) studied the correspondence between caloric, cVEMP and oVEMP test to see association between them to diagnose peripheral vestibular disorders. They found that oVEMP test has an association with caloric test results which indicates that the oVEMP test may be interchangeably used instead of the caloric test for diagnosing the pathologies the vestibular nerve. Along with, the caloric, oVEMP, and cVEMP tests should be administer to diagnose the site of lesion in the vestibular system. An association exists between caloric and o-VEMP test results, but neither between caloric and c-VEMP test results, nor between o-VEMP and c-VEMP test results.

Diagnosis with electronystagmography in early stage of disease helps in better prognosis. Junicho et.al. (2008) did a retrospective study of 1,334 subject medical records to see the outcome of the treatment of initial electronystagmography results in subjects with idiopathic sudden sensorineural hearing loss without vertigo. Results suggest that the initial ENG findings could provide prognostic information for idiopathic SSHL patients, even those who have no vestibular symptoms at the first visit.

High level of hearing loss indicates more damage to the inner ear mechanisms. Wilson et al. (1982), studied electronystagmographic findings for 116 patients with unilateral idiopathic sudden hearing loss. There was an association between both subjective vertigo and abnormal ENG findings and the profound hearing loss at the onset of ISHL. Abnormal ENG findings coexisted with more severe hearing loss at onset of ISHL and showed lesser improvement of hearing than did subjects who had normal ENG response. Less improvement was observed in the high frequencies than from those in the low frequencies in subjects with abnormal ENG findings attributing to anatomical propinquity of the basal turn of the cochlea to the vestibular system.

Bergenius (1985), studied vestibular findings in sensorineural hearing disorders, in 205 patients with unilateral hearing loss, thorough audio vestibular examinations were performed to establish the occurrence and severity of vestibular dysfunction. No correlation was found between severity of hearing loss and recordable vestibular dysfunction. The relations between audiometric hearing test pattern, caloric sensitivity and oculomotor disturbances seem to form interesting diagnostic paradigms of great value for the topical localization of audio vestibular disorders.

Abnormal functioning of saccule has been found in individuals with idiopathic sudden sensorineural hearing loss (ISSHL). Hong et.al (2008) studied saccular damage in patients with ISSHL without vertigo in 52 subjects with idiopathic sudden sensorineural hearing loss. They found that abnormal VEMP responses might be observed in ISSHL patients who do not have vertigo. These findings suggest that the vestibular system, in particular the saccule, has a subclinical involvement in ISSHL patients.

Sudden sensorineural hearing loss affects both cochlea and vestibular system. Rajati et. al. (2011) studied VEMP in sudden sensorineural hearing loss in about 40% of patients experience vertigo or imbalance. Out of 43 subjects, 14 (32.6%) had vertigo, 43 had a abnormal VEMP and in the 30 subjects VEMP was normal. In SSNHL the pathology is not limited to the cochlea and even in patients with no vestibular symptoms saccule might be involved.

Vestibular assessment may be valuable in predicting the final outcome in sudden sensorineural hearing loss. Korres et.al., (2011) studied correlation between caloric and cVEMP test results in subjects with unilateral sudden senosrineural hearing loss. One hundred and four patients underwent complete neurotological evaluation. They found that overall, abnormal vestibular evoked myogenic potential responses occurred in 28.8 per cent of patients, whereas abnormal caloric test results occurred in 50 per cent. A statistically significant relationship was found between the type of inner ear lesion and the incidence of profound hearing loss. There was no significant difference between cVEMP and caloric testing.

Vestibular responses depend upon the severity of hearing loss and initial average hearing threshold. Lee et.al. (2010) they reported about 30-40% of patients with idiopathic sudden unilateral sensorineural hearing loss have associated vertigo. They investigated that the results of VEMP test and caloric responses in 48 patients, normal VEMP response was observed in 17 subjects (35.4%) and VEMP was abnormal in 10 patients (20%) and abnormal caloric results were seen in 24 patients (50%). There was an association between the abnormal VEMP, caloric response and hearing loss type. When the severity of hearing loss is very high, VEMP become more prone to get affected.

Saccule is more frequently affected than semicircular canals in unilateral sudden sensorineural hearing loss. Iwasaki et.al. (2005), studied the amount of the vestibular damage in unilateral sudden hearing loss with vertigo using click evoked VEMP and caloric tests. 22 patients with unilateral sudden hearing loss with vertigo were taken. Poorer side showed absent VEMP in 17 (77%), and absent caloric response in 10 subjects (45%). There was an association between the caloric and VEMP, subjects with absent caloric response 90% showed abnormal responses for VEMP too. The combined use of click-VEMP and caloric tests is useful for evaluating vestibular functions in unilateral sudden hearing loss with vertigo because the extent of vestibular abnormalities correlated well with hearing outcome.

Wu & Young, (2002), they evaluated VEMPs in cases of sudden hearing loss. They enrolled 20 subjects with unilateral idiopathic sudden hearing loss. The results were compared between poorer side, better side and with individuals with normal hearing in both sides. All 20 of the subjects showed normal biphasic VEMPs in the affected side. Absent caloric response was seen in 5 ear, and 15 ears showed normal caloric response. VEMPs showed no correlation with the hearing loss and to the caloric response.

Vestibular testing in individuals with unilateral SNHL helps in predicting the prognosis in them. Wang et. al. (2009), studied whether audio- vestibular function tests, which are auditory brain stem response (ABR) and VEMP tests were concurrent to hearing recovery after making other causes of severe to profound sudden unilateral sensorineural hearing loss under control. They recommended that both ABR and VEMP tests should be included in the battery of neuro- otological examinations in patients with severe sudden unilateral hearing loss because the presence of waveforms in both tests might indicate favourable hearing recovery. The presence of vertigo might portend a worse prognosis in patients with profound unilateral sudden sensorineural hearing loss.

In summary ENG, cVEMPs and oVEMPs found to be valuable in diagnosis of various vestibular disorders. ENG, cVEMPs and oVEMPs found to be assessing different vestibular reflex pathways. There is a dearth of information regarding the combination of caloric, cVEMPs and oVEMPs in individuals with vestibular dysfunction in unilateral sensorineural hearing loss. So the present study was taken up to assess different vestibular reflex pathway in individuals with unilateral sensorineural hearing loss. An association was found between caloric and oVEMP test results, but neither between caloric and c-VEMP test results nor between o-VEMP and c-VEMP test results (Huang et.al. 2012).

Chapter 3

Method

The purpose of the present study was to assess different vestibular pathways (Semicircular canal ocular reflex pathway, Vestibulo-collic reflex pathway & Otolith-ocular reflex pathway) in individuals with unilateral sensorineural hearing loss. To test the integrity of these pathways caloric test, cervical vestibular evoked myogenic potential (cVEMPs) & occular vestibular evoked myogenic potential oVEMPs were administered.

Participants

10 males (20 ears) participants ranging in age from 17-55 years with a mean age of 34 years were considered for the study.

Participant selection criteria

a. Participants having unilateral sudden sensorineural hearing loss average air conduction thresholds of 50 dB HL or greater in the affected ear with normal hearing in the other ear being considered less than or equal to 15 dBHL were considered for the study.
b. Participants with or without vestibular symptoms were considered.
c. Participants had normal middle ears function as evidenced by the immittance evaluation and report from the otolaryngologist.
d. None of the participants had history or presence of any ear pain or ear discharge.
e. None of the participants had any associated neurological problems.
f. Participants did not have history of neuromuscular problems in neck region.

g. Participants did not have any history of obvious vestibular pathology such as Meniere's disease, labrynthitis, vestibular neuritis.

h. Participants had uncomfortable loudness level greater than 100 dBHL.

i. None of the participants had retrocochlear pathology as evidenced by auditory brainstem response and report from Neurologist.

Instrumentation:

1. A calibrated two channel OB-922 diagnostic audiometer with TDH-39 headphones and B-71 bone vibrator for administering pure tone audiometry and uncomfortable loudness level measurements.
2. A calibrated GSI-TympStar middle ear analyzer for administrating tympanometry and acoustic reflexes, using 226Hz probe tone.
3. Calibrated Biologic Navigator Pro Evoked potential system to record ABR and oVEMP. Biologic insert earphone was used to deliver the stimuli.
4. Calibrated IHS (Intelligent Hearing System) Smart EP (3.94 USBez) system was used for recording air conducted tone bursts evoked cVEMP. Calibrated Eartone 3A insert earphone was used to deliver the stimuli.
5. RMS ENG instrument was used to record caloric test. Open water loop irrigators were used to inject hot and cold water.

Test Environment

All the testing was done in sound treated rooms where the noise levels were as per the guidelines in ANSI S 3.1 (1991).

Test Procedure

Case History: A thorough case history was taken for each client before testing. Questionnaire was administered through interview method which comprises of several questions related to the dizziness and frequency of occurrence.

Pure tone thresholds: Pure tone hearing thresholds were measured using modified Hughson Westlake method (Carhart & Jerger, 1959). Threshold was obtained across octave frequencies 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction using Calibrated OB-922 diagnostic audiometer.

Uncomfortable Level: Uncomfortable loudness level measurement for speech was done for all the clients. Ascending method was used to measure UCL.

Tympanometry: Tympanometry was carried out with a probe tone frequency of 226Hz. Ipsilateral and contralateral acoustic reflexes thresholds was measured for 500, 1000, 2000 and 4000Hz.

Auditory Brainstem Evoked Response: Auditory Brainstem Response was recorded with repetition rates of 11.1/s and 90.1/s at the intensity level of 90 dBnHL for a click stimulus of rarefaction polarity, band pass filtered between 100Hz to 3000Hz. The conventional electrode placement was used non-inverting on high- forehead, inverting on both the test ear mastoid and ground on lower forehead.

Cervical Vestibular Evoked Myogenic Potential (cVEMP)*:* The clients were seated comfortably in a reclining chair. The skin surface of the testing site was cleaned with skin abrasive gel, to obtain the absolute electrode impedance of less than 5 kΩ and inter-electrode impedance of less than 2 kΩ. The electrodes were placed with the help of skin conduction paste and secured tightly in their respective places using surgical plaster. Silver chloride disc electrodes were used for recording. Subjects were instructed to maintain the tonicity of the sternocleidomastoid muscle for the cervical VEMP by sitting straight and turn their head to the opposite side of the ear in which stimulus was presented. IHS instrument has EMG monitoring device, where the muscle tension has to be maintained between 50μv to 100μv. This monitoring system ensures uniform muscle tension across all the participants. A visual feedback was provided to the participant in order to maintain the tonicity of the stenocleidomastoid muscle. The stimulus and acquisition parameters used to record c- VEMP are given in Table-3.1.

Table 3.1

Stimulus and Acquisition parameters used to record c-VEMP

Stimulus Parameters

Stimulus	**Settings**
Transducer	Insert ear phones
Type	Tone burst
Frequency	500 Hz
Intensity	95dBnHL
Duration	2-0-2 Cycles
Acquisition Parameters	
Stimulus polarity	Rarefaction
Stimulus Rate	5.1/s
Time window	
Pre stimulus	10 ms
Post stimulus	50 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 (+)	Sternoclediomastoid muscle
Ground electrode	Forehead

Occular Vestibular Evoked Myogenic Potential (oVEMP): Subjects were instructed to maintain upward gaze while recording oVEMP. The sites of electrode placement were prepared with skin preparing gel, for getting good skin impedance. Surgical tape was used to fix the electrode on the electrode sites. Inverting electrode was placed on 1 cm below to inferior oblique muscle contralaterally to ear stimulated, non-inverting electrode was placed immediately below the inverting electrode and ground electrode was placed on lower forehead. Absolute electrode impedances and inter electrode impedance should not exceed 5 KΩ and 2 KΩ respectively. oVEMP was recorded in contralateral mode. The stimulus and acquisition parameters used to record o-VEMP are given in Table-3.2.

Table 3.2

Stimulus and Acquisition parameters used to record o- VEMP

Stimulus Parameters

Stimulus	**Settings**
Transducer	Insert ear phones with 0.8ms delay
Type	Tone burst
Frequency	500 Hz
Intensity	95dBnHL
Duration	2-0-2 Cycles
Acquisition Parameters	
Stimulus polarity	Rarefaction
Stimulus Rate	5.1/s
Time window	
Pre stimulus	10 ms
Post stimulus	50ms
Filter setting	10 to 1000 Hz
Amplification	5000
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

Electronystagmogaphy: The caloric test was performed with the subject reclining, head inclined 30^0 above the horizontal plane so as to make the lateral semicircular canal into vertical plane, where it can be maximally stimulated. Open loop water irrigation was introduced into the ear canal. The temperature selected for warm stimulation was 44^0 C and temperature for cold stimulation was 30^0 C. 20ml of water was taken in syringe and irrigated in the subject's ear canal for the period of 30 secs. The nystagmus obtained on the four recordings i.e. Right warm, Right Cold, Left warm and Left cold was analyzed. Recording was done for the 2 minutes after each type of the irrigation. 7 minutes inter-irrigation timing was given during the recording. The cognitive task was also given to avoid the attention towards the stimulation. Table 3.3 shows the recording protocol for the caloric test.

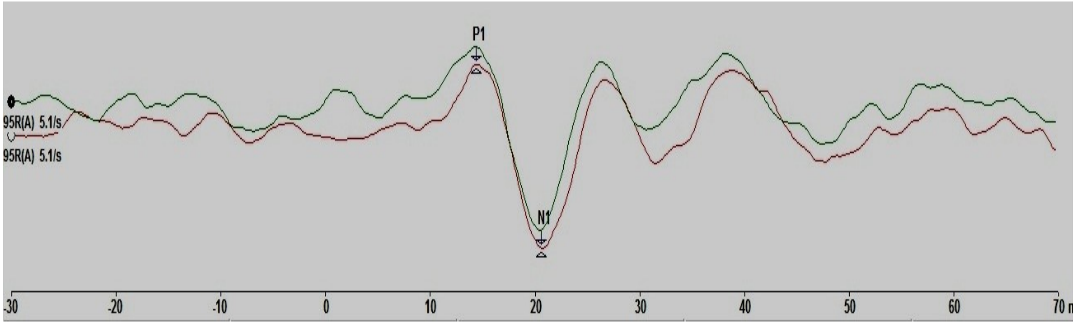
Table 3.3

Recording Protocol for Caloric test

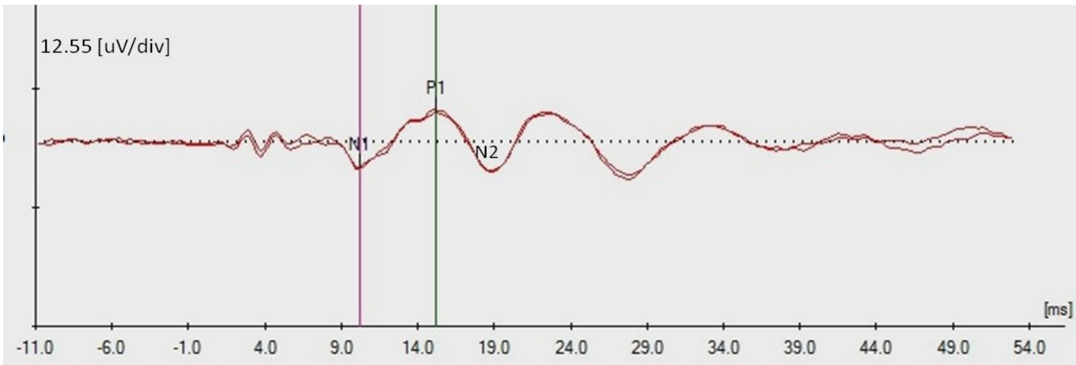
Parameter	**Setting**
Band-pass filter	0.1 Hz to 30 Hz
Notch filter	On
Gain	Gain of the incoming signal was adjusted in such a way that 10 mm deflection of recording pen represents 200 µv of corneoretinal potentials
Number of channels	1.00
Electrode placement	Non-inverting electrode (+): outer canthus of the right eye, inverting electrode (–): outer canthus of the left eye, and ground electrode: lower forehead

Response Analysis

- For cVEMP responses, latency and amplitude of P1, N1 and complex of P1 – N1 was analysed for each subject.



- For oVEMP, latency and amplitude of N1, P1, N2 peaks and amplitude complex of N1-P1 & P1- N2 was analysed for each subject.



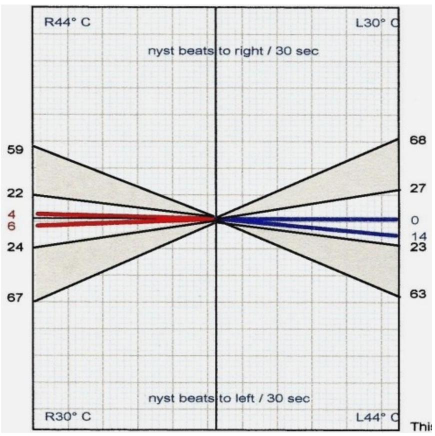
- For caloric test, the hyperactivity and hypoactivity of the responses was analysed with the help of Claussen's Butterfly chart. To plot the results in butterfly chart the culmination frequency was calculated. This culmination frequency was calculated in all 4 simulation conditions.

Culmination Frequency:

The entire tracing of nystagmus is divided into 10 second intervals. The number of beats in each 10 second interval is counted. The 3 adjacent 10 second intervals, showing together the highest number of beats, constitute the culmination phase. The total number of beats in this culmination phase of 30 seconds is noted. The culmination frequency is then indicated as the number of beats per 30 seconds.

Butterfly Chart:

The data obtained from the evaluation of caloric nystagmus reactions are represented on a synoptical chart. The chart consists of 4 quadrants, each representing one caloric reaction. In each quadrant, the abscissa or the horizontal axis represents time (30 seconds of the culmination phase) and the ordinate or the vertical axis represents the number of nystagmus beats (culmination frequency). The number of nystagmus beats per 30 seconds in the culmination phase of the caloric response is plotted on the vertical axis. The normal range of caloric is superimposed on the vertical axis of the quadrant. Responses within this range are considered normal and those below it as hypoactive and those above it as hyperactive. The Butterfly Chart consists of four such quadrants for the four caloric reactions, each with its corresponding normal range. The nystagmus reactions beating to the right are represented above the horizontal axis, while those beating to the left are represented below it. Hence, starting with the R 44^0 C, the order of quadrants in an anti clockwise direction is R 44^0 C, R 33^0 C, L 44^0 C, and L 33^0 C.



Chapter- 4

Results and Discussion

The present study was designed to assess the functioning of different vestibular pathways using caloric test, cervical vestibular evoked myogenic potentials (cVEMPs) test and ocular vestibular evoked myogenic potentials (oVEMPs) test in individuals with unilateral sensorineural hearing loss.

To achieve the aim, total 10 subjects (20 ears) with unilateral sensorineural hearing loss were evaluated using the vestibular evoked myogenic potentials (cVEMPs and oVEMPs) and caloric test.

4.1 Vestibular test findings in individuals with unilateral sensorineural hearing loss

The clinical information of the 10 participants with unilateral sensorineural hearing loss is given in table 4.1.

Table 4.1

Clinical information of 10 participants with unilateral sensorineural hearing loss

Subject No	Age (years)	Ear	Air conduction thresholds (dBHL)						ABR
			250 Hz	500 Hz	1kHz	2kHz	4kHz	8kHz	
1	46	L	90	95	90	90	70	70	A
		R	20	10	5	5	5	5	P
2	42	R	90	110	95	90	90	90	A
		L	10	15	15	10	5	5	P
3	38	R	90*	120*	120*	120*	110*	100*	A
		L	15	10	10	15	10	15	P
4	50	L	90	95	100	115	110*	100*	A
		R	5	5	10	10	5	10	P
5	19	L	90	95	95	120*	110*	100*	A
		R	10	10	15	15	15	10	P
6	39	R	90	90	100	120*	110*	100*	A
		L	20	15	15	15	10	10	P
7	56	R	50	55	60	65	70	70	A
		L	10	10	15	15	15	15	P
8	42	R	85	95	100	110	110*	100*	A
		L	10	10	15	15	10	10	P
9	42	L	80	80	85	85	90	100*	A
		R	20	15	15	10	15	15	P
10	19	L	90*	120*	120*	120*	110*	100*	A
		R	15	15	10	10	10	10	P

A – Absent, P- present, ABR – auditory brainstem response, L- left, R-right, * - no response

It can be seen in Table 4.1 that most of the subjects had severe to profound hearing loss in the affected ear, whereas in other ear the auditory thresholds are within normal limits.

4.1.1 Cervical vestibular evoked myogenic potentials test results in affected ear

Latency of P1 peak and latency of N1 peak and amplitude of P1- N1 complex were analysed. The response pattern of cVEMPs recorded from one individual with unilateral sensorineural hearing loss is shown in figure 4.1.

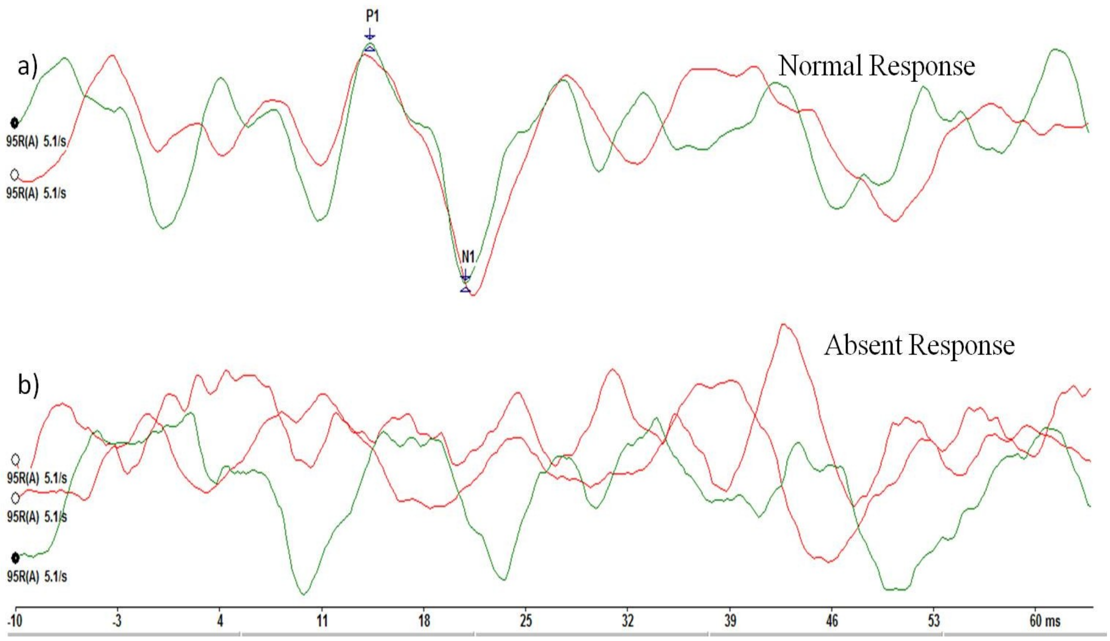


Figure 4.1 cVEMP response to 500 Hz tone burst at 95 dBnHL stimuli in one individual with unilateral sensorineural hearing loss (a) Normal cVEMPs response (b) Absent cVEMPs response.

Out of 10 ears with unilateral sensorineural hearing loss, 9 ears had absence of cVEMPs responses (90%) and 1 had presence of cVEMP responses (10%). In one ear where cVEMPs was present the latency of P1 was 14.60ms, latency of N1 was 21.20ms and amplitude of P1-N1 complex was 23.45μV.

4.1.2 Ocular vestibular evoked myogenic potentials test results in affected ear

Latency of N1, latency of P1 & latency of N2 and amplitude of N1-P1 & P1-N2 complex were analysed. The response patterns of oVEMPs recorded from one individual with unilateral sensorineural hearing loss are shown in figure 4.2.

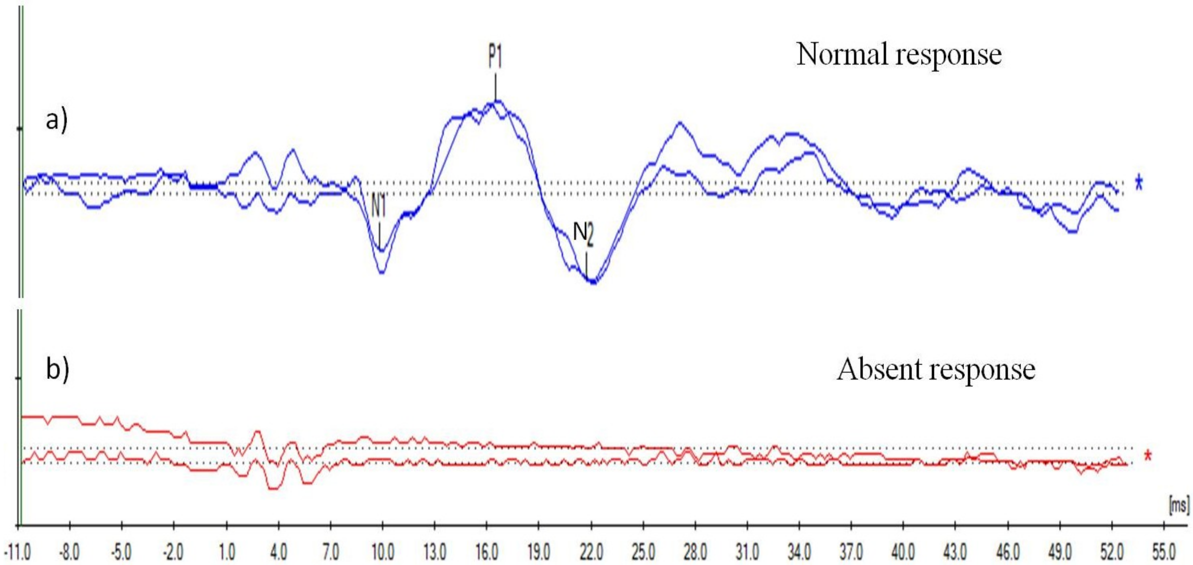


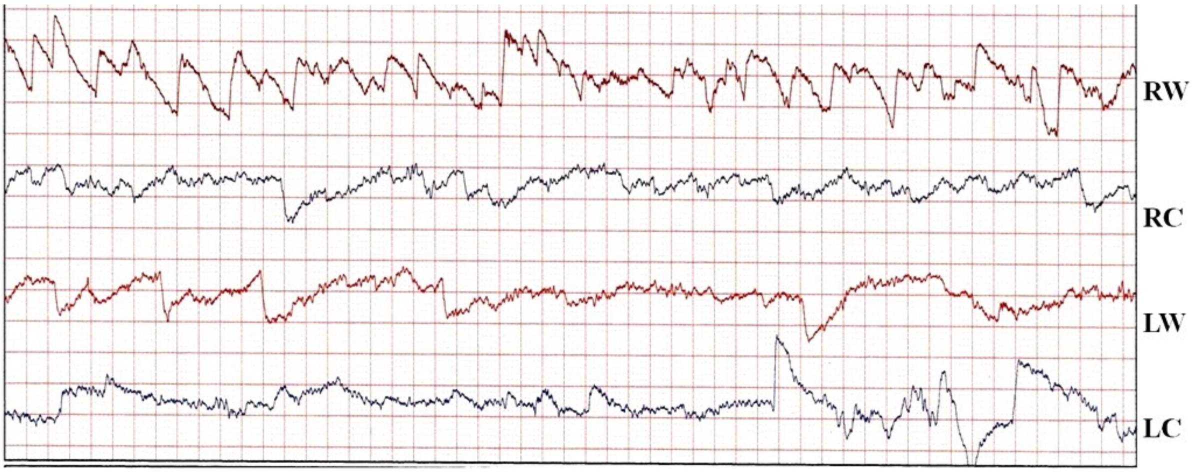
Figure 4.2 oVEMP response to 500 Hz tone burst at 95 dBnHL stimuli in one individual with unilateral sensorineural hearing loss (a) Normal oVEMP response (b) Absent oVEMP response

In oVEMPs recordings, out of 10 ears with unilateral sensorineural hearing loss, 8 ears had absence of oVEMPs responses (80%) and 2 had normal responses (20%). Out of the normal responses, for one subject the latency of N1 was 10.7ms, P1 was 17.45ms & for N2 was 23.20ms. Amplitude of N1-P1 complex was 6.75µV & for P1-N2 was 5.75 µV. For second subject the latency for N1 was 9.95ms for P1 was 16.70ms & for N2 was 20.70ms. Amplitude of N1-P1 complex was 5.25 µV & for P1-N2 was 4.75 µV.

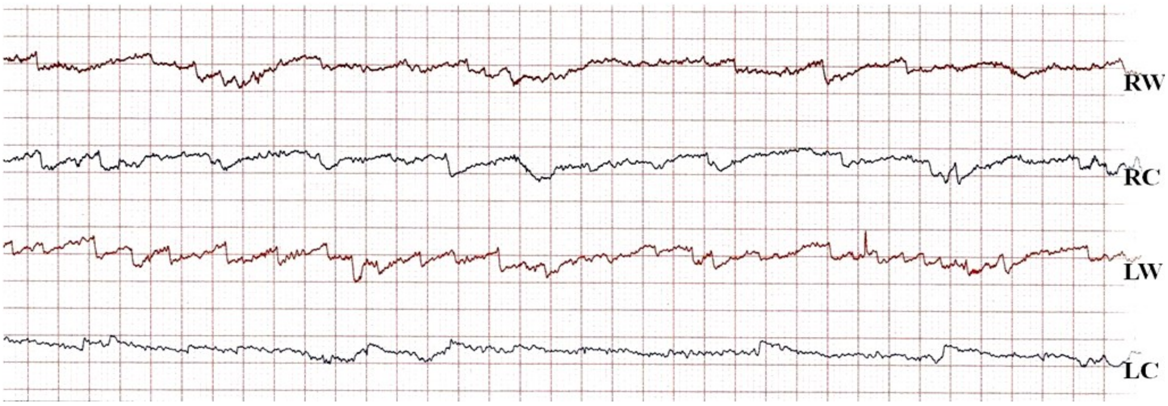
4.1.3 Caloric Test results in unilateral sensorineural hearing loss in affected ear

Out of 10 ears with unilateral sensorineural hearing loss, Caloric test results showed hypoactivity in all 10 ears (100%) to caloric stimulation. Figure 4.3 shows the recorded caloric tracings for all the 10 subjects.

Subject 1



Subject 2



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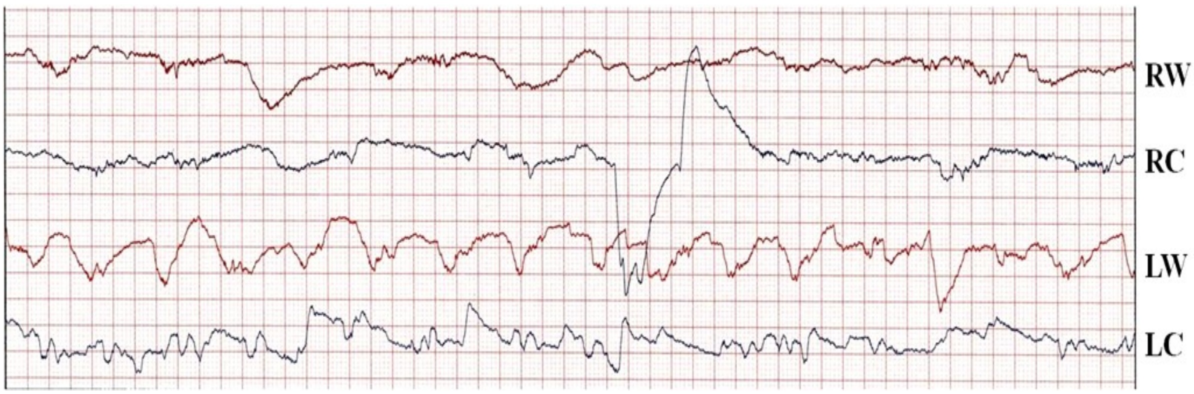
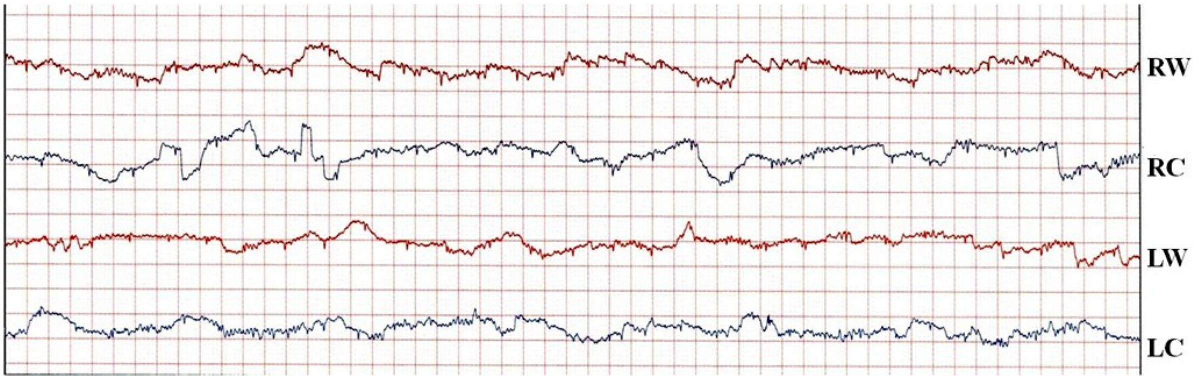


Subject 4



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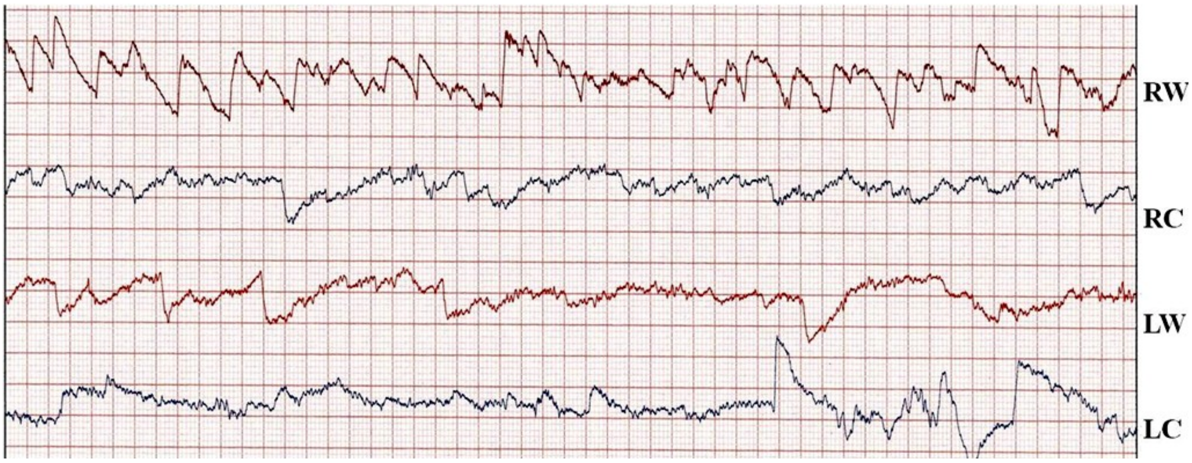

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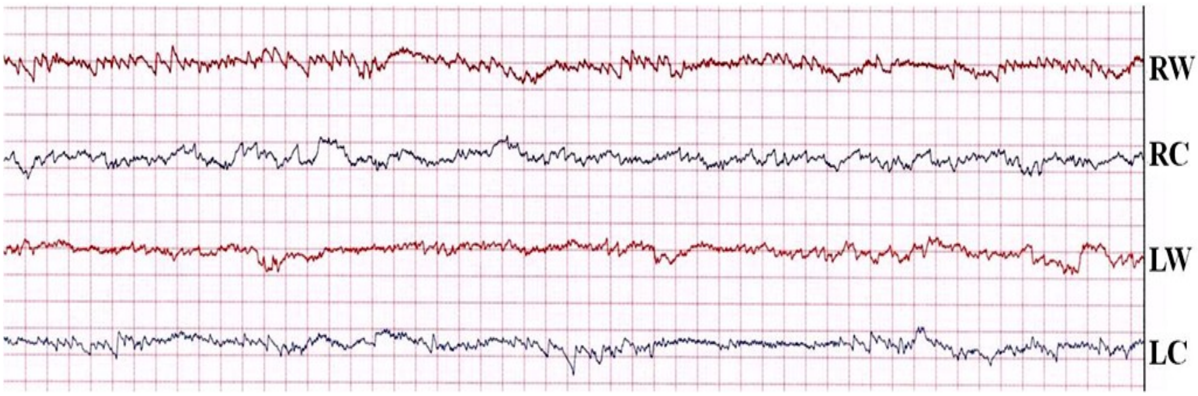
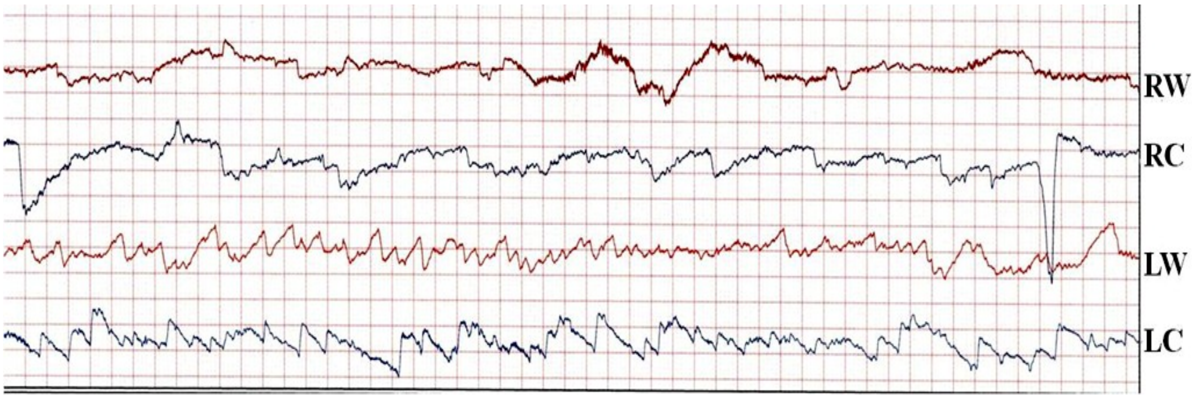


Subject 7



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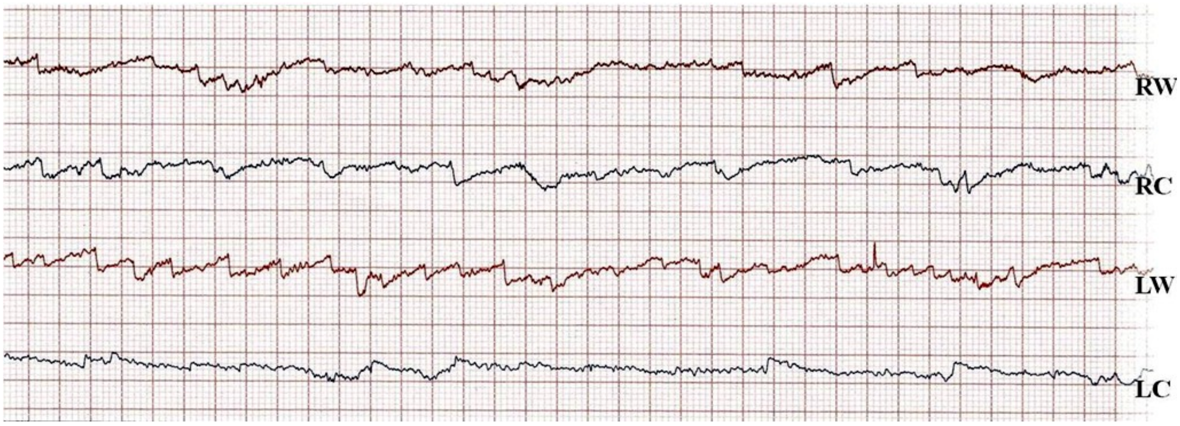
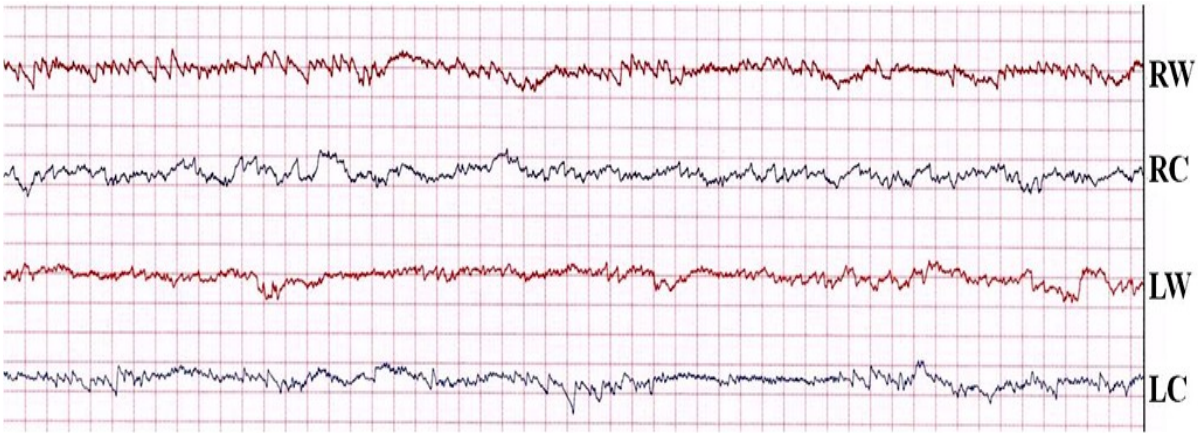


Subject 9



Subject 10

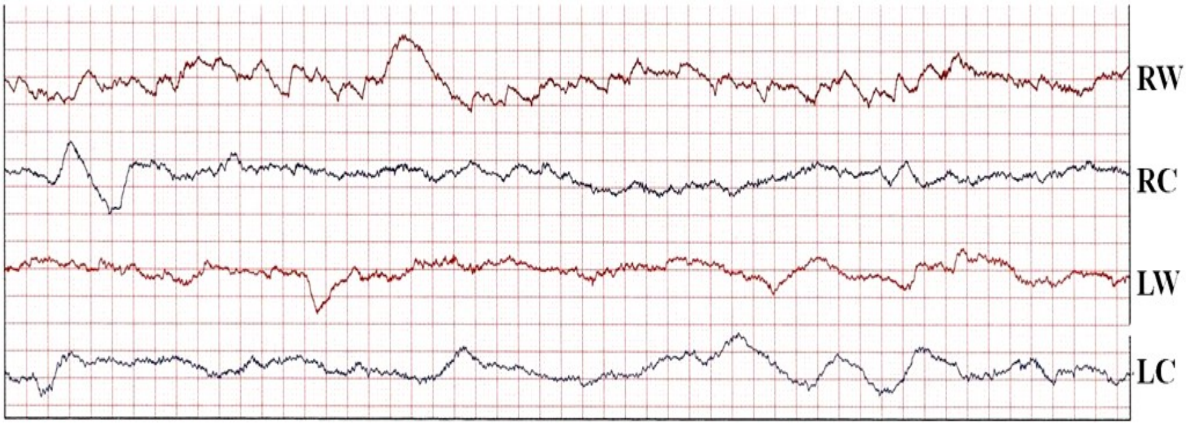
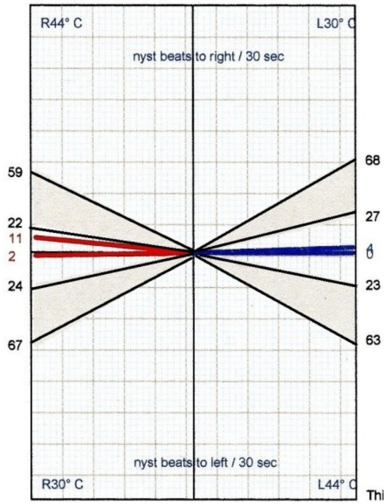
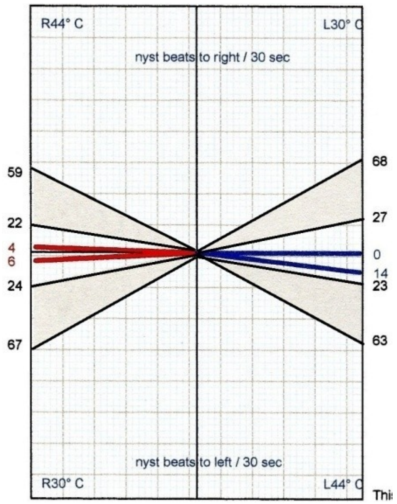
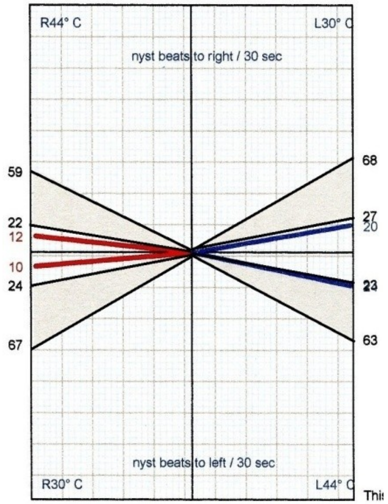


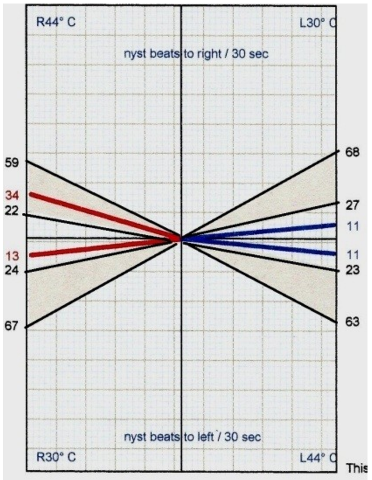
Figure 4.3 Caloric tracings for all the 10 participants.

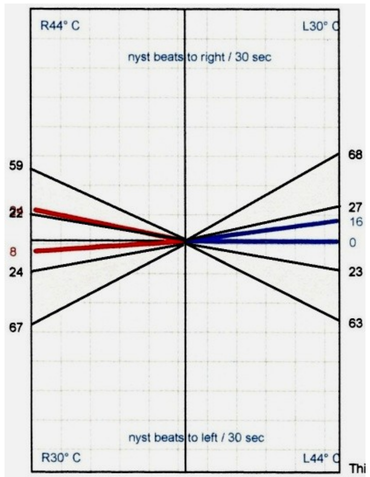
The figure 4.3 indicates hypoactivity in caloric responses. The culminative frequency was calculated for all the tracings for all the participants. Based on culminative frequency Butterfly chart was made. Figure 4.4 shows Butterfly chart from all the ten participants. .

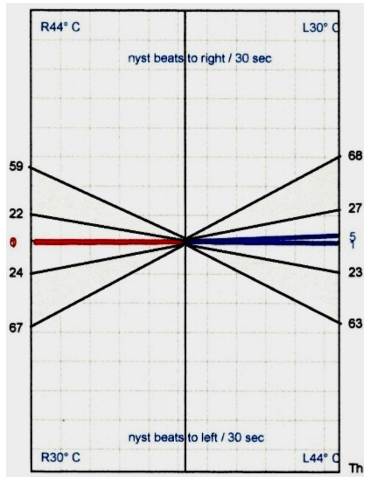

R44° C
L30° C
nyst beats to right / 30 sec
59
22
11
2
24
67
68
27
23
63
nyst beats to left / 30 sec
R30° C
L44° C


R44° C
L30° C
nyst beats to right / 30 sec
59
22
4
6
24
67
68
27
0
14
23
63
nyst beats to left / 30 sec
R30° C
L44° C


R44° C
L30° C
nyst beats to right / 30 sec
59
22
12
10
24
67
68
27
20
63
nyst beats to left / 30 sec
R30° C
L44° C


R44° C
L30° C
nyst beats to right / 30 sec
59
34
22
13
24
67
68
27
11
11
23
63
nyst beats to left / 30 sec
R30° C
L44° C


R44° C
L30° C
nyst beats to right / 30 sec
59
8
24
67
68
27
16
0
23
63
nyst beats to left / 30 sec
R30° C
L44° C


R44° C
L30° C
nyst beats to right / 30 sec
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27
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23
63
nyst beats to left / 30 sec
R30° C
L44° C

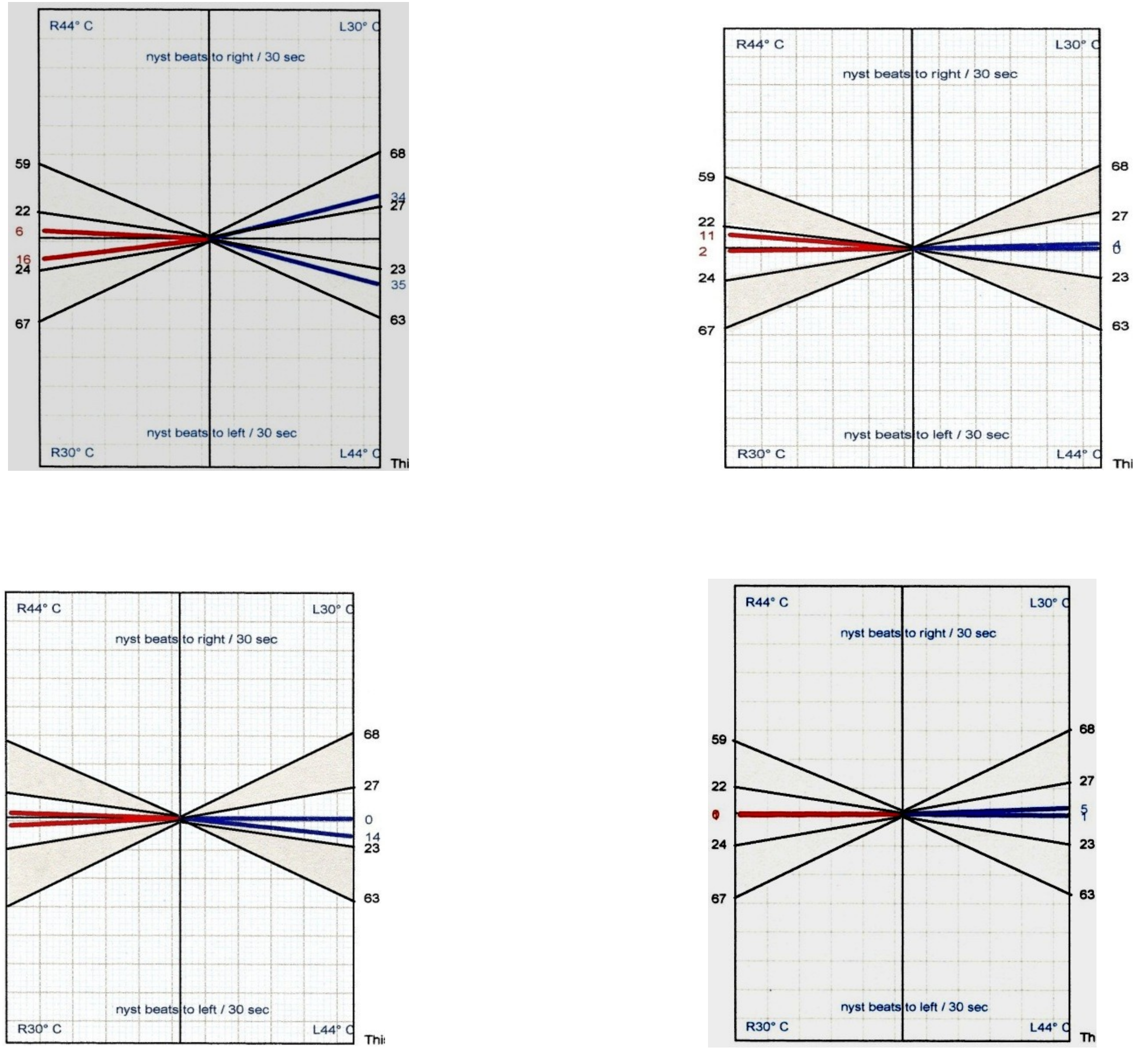

Figure 4.4 Butterfly chart for all the 10 subjects.

In the present study cVEMP was absent in 90% of the participants with unilateral sudden sensorineural hearing loss. In literature, the prevalence of absence of cVEMP varies across studies. Rambold et al. (2005) reported that in 45 % of the subjects with unilateral sudden sensorineural hearing loss cVEMP is absent, Iwasaki et al. (2005) reported absence of cVEMP in 77% of the participants with unilateral hearing loss, whereas Lee et al. (2001) reported an absence of cVEMP responses in 20% of the participants with unilateral sudden sensorineural hearing loss. In the present study, the cVEMP was absent in 90% of the subjects with unilateral sudden sensorineural hearing loss, which is higher compared to the earlier studies. The variability of the cVEMP results across the studies could be attributed to the age of the participants, methods of recording cVEMP (i.e rectified versus unrectified method), and the etiological factors of the unilateral sudden sensorineural hearing loss (as it has been reported that there are various causes for the unilateral sudden sensorineural hearing loss).

The variability could also be attributed to duration between the onset of the symptoms and the cVEMP testing. In the present study, the participants were tested for cVEMP, from one month to 432 months post onset of symptoms which is higher compared to the previous studies reported in the literature (Hong et al. 2008; Lee et al 2010). It is hypothesised that the saccular damage would have been irreversible in the participants of the present study since the duration between the onset of the disorder and cVEMP testing was more.

In the present study the oVEMP was absent in 80% of the participants. In a previous study Cho et al.(2011) reported that oVEMP was absent in 67% of the participants. Cho et al. (2011) also reported that the response rate of cVEMP and oVEMP is almost similar in participants with unilateral sudden sensorineural hearing loss and hence it is postulated that not only the saccule but also the utricular system is affected in individuals with unilateral sudden sensorineural hearing loss. Thus, the oVEMP responses were absent in 80% of the subjects in the present study.

In the present study, 100% of the ears with unilateral sensorineural hearing loss, caloric responses were absent. The results were based on comparison to the normative established in a previous study done by Sarvanan (2012). The prevalence of absence of caloric responses varies across the studies. Korres et al. (2011) reported abnormal caloric test findings in 50% of individuals with sudden sensorineural hearing loss, Pajor et al. (2002) reported abnormal responses in 72% of the individuals with unilateral sensorineural hearing loss. Also, Murofushi et al (2011) reported absence of caloric responses in 90% of the subjects. The variability in caloric responses could be due to the duration of the disorder, age of the clients, aetiological factors causing damage to the crista ampullaris and also the severity of the damage in participants with unilateral sudden sensorineural hearing loss.

As it is seen that all the vestibular tests showed absence of responses in various tests in most of the participants, it indicates that the pathology is not restricted to a particular structure in the vestibular system rather than the whole vestibular system is affected in these individuals. As it is well known that the vestibular system and cochlear system in confined within the same cavity and also both the system shares the same fluid i.e endolymph. Also, there is a great similarity between the cochlear and vestibular hair cells and the common arterial blood supply to the cochlea via the same end artery supports the possibility of involvement of cochlear as well as vestibular system in individuals with idiopathic sudden sensorineural hearing loss.

Various structural changes such as loss of vestibular hair cells in the vestibular system, such as loss of saccular hair cells, loss of hair cells in posterior ampulla

(Gussen, 1976; Sando et al. 1977), posterior rupture of the ampulla walls (Gussen, 1976; Sando et al. 1977), reduction in the total number of hair cells in the vestibular system (Yoon et al. 1990) etc has been reported in individuals with idiopathic sudden sensorineural hearing loss. These changes in the hair cells of the vestibular system or the reduction in number of vestibular hair cells will lead to the alteration of the responses from the vestibular system. Hence the potentials recorded from the vestibular system will reduce or will be absent. It is assumed that there was a generalised loss of the hair cells in the participants subjected in the present study and hence it was absent in these participants.

4.2 Association of Caloric test, cVEMPs and oVEMPs results in subjects with unilateral sensorineural hearing loss in affected ear

As, the caloric test results, cVEMPs results & oVEMPs test results were affected differentially in different participants Chi-square test was done to find out if any association exists between caloric, cVEMPs and oVEMPs test results. The details of Chi-square test are given in table 4.2.

Table 4.2

Association of caloric test, cVEMPs and oVEMPs results in subjects with unilateral sensorineural hearing loss

Test		**oVEMPs**			**cVEMPs**		
		Normal	**Abnormal**	**Total**	**Normal**	**Abnormal**	**Total**
Caloric test	Normal	0	0	0	0	0	0
	Abnormal	2	8	10	1	9	10
	Total	2	8	10	1	9	10
cVEMPs	Normal	0	1	1			
	Abnormal	2	7	9			
	Total	2	8	10			

It can be seen from the Table 4.2 that cVEMPs are abnormal in 90%, oVEMPs are abnormal in 80% and caloric responses are abnormal in 100% of subjects with unilateral sensorineural hearing loss. The same findings can be seen in the bar graph also. This can be visualised in figure 4.5.

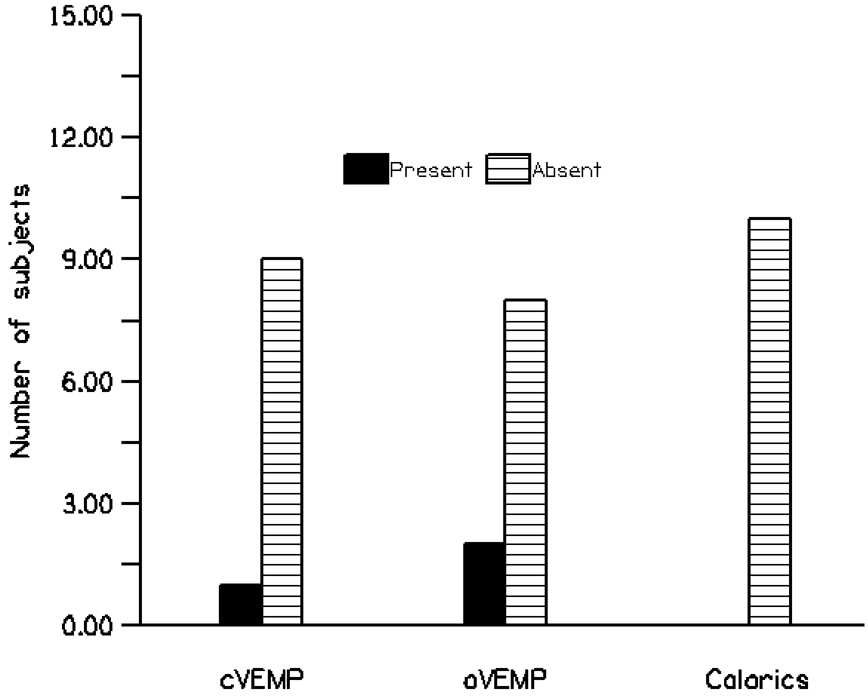

Figure 4.5 c*VEMPs*, oVEMPs and caloric responses of subjects with unilateral sensorineural hearing loss.

Chi-square test results revealed an association between presence or absence of cVEMP and oVEMP responses in subjects with unilateral sensorineural hearing loss (p= 0.03). Chi-square could not be administered to find out the association between the caloric & cVEMP and caloric & oVEMP as the result of caloric test were constantly absent in all the ears.

In the present study, in one of the participant had presence of cVEMP but absence of oVEMP, whereas in another 2 participants oVEMP was present but cVEMP was absent. Also, in 7 participants both cVEMP and oVEMP were absent. Chi-square test showed a significant association between the cVEMP and oVEMP tests findings. Previous study by Cho et al (2011) also reported that the cVEMP and oVEMP responses were not different from each other. This finding implies that there is no differential damage in the vestibular system of the individuals with unilateral sudden sensorineural hearing loss. Thus, combining the three tests would provide a complete picture of the damage caused in the vestibular system of the individuals with unilateral sensorineural hearing loss.

4.3 Association between duration of the hearing loss with vestibular test results in affected ear

As, Table 4.3 shows the information on duration of hearing loss and vestibular test findings in subjects with unilateral sensorineural hearing loss in affected ear.

Table 4.3

Association of vestibular tests with the duration in subjects with unilateral sensorineural hearing loss in affected ear

Subject no.	Duration of hearing loss (in months)	cVEMP	oVEMP	Caloric
1	12	Present	Absent	Absent
2	1	Absent	Absent	Absent
3	24	Absent	Absent	Absent
4	36	Absent	Absent	Absent
5	12	Absent	Present	Absent
6	432	Absent	Present	Absent
7	8	Absent	Absent	Absent
8	240	Absent	Absent	Absent
9	24	Absent	Absent	Absent
10	36	Absent	Absent	Absent

Chi-square test was done to find out if any association exists between duration of hearing loss and caloric, cVEMPs & oVEMPs test results.

Chi-square test results revealed no association between duration of hearing loss and cVEMP (p=0.61) and also there was no association between duration of hearing loss and oVEMP (p=0.71) in subjects with unilateral sensorineural hearing loss. Chi-square could not be administered to find out the association between the caloric and duration of hearing loss as the result of caloric test were constantly absent in all the ears.

In the present study, there was no correlation between the cVEMP and oVEMP findings and duration of the disease. The VEMP responses have been reported to be absent in individuals with sudden sensorineural hearing loss as early as within 3 days of onset (Cho et al. 2011). Since in the present study cVEMP testing in individuals with sudden sensorineural hearing loss was done much later (minimum one month after the onset in one participant), the responses were absent in almost all the participants and hence statistical test was not able to show any significant association between the duration of the disorder and the cVEMP and oVEMP test results findings.

4.4 Association between degrees of hearing loss of the hearing loss with vestibular test results in affected ear

As, the caloric test results, cVEMPs results & oVEMPs test results were affected differentially in different participants Chi-square test was done to find out if any association exists between degree of hearing loss and caloric, cVEMPs & oVEMPs test results. The details of Chi-square test are given in table 4.4.

Table 4.4

Association of caloric test, cVEMPs and oVEMPs with the degree of hearing loss in subjects with unilateral sensorineural hearing loss in affected ear

		Degree			Total
		Moderately severe	Severe	Profound	
oVEMP	Absent	1	4	3	8
	Present	0	1	1	2
cVEMP	Absent	1	5	3	9
	Present	0	0	1	1
Caloric	Absent	1	5	4	10
	Present	0	0	0	0

Chi-square test results revealed no association between degree of hearing loss and cVEMP (p=0.43) and also no association between degree of hearing loss and oVEMP (p=0.85) in subjects with unilateral sensorineural hearing loss. Chi-square could not be administered to find out the association between the caloric and degree of hearing loss as the result of caloric test were constantly absent in all the ears.

It has been reported that the greater degree of hearing loss indicates a more severe damage of the inner ear mechanism (Wilson et al. 1982). In the present study, for most of the participants the hearing loss was in severe to profound category but for one participant in whom the degree of hearing loss of moderately severe degree. Since in most of the participants the hearing loss was in severe to profound degree, there would have been an extensive damage to the cochlear as well as vestibular system in these participants. Also, because most of the subjects the responses were absent, the statistical analysis would have failed to show any significant association because of a small data.

4.5 Vestibular test findings in contralateral ears of individuals with unilateral sensorineural hearing loss in normal ears

The normal ears of individuals with unilateral sensorineural hearing loss were also evaluated to find out if any pathology exists in the normal ear also. The clinical information of individuals with unilateral hearing loss is shown in Table 4.1.

4.5.1 Cervical vestibular evoked myogenic potentials test results in normal ear

Latency of P1 and latency of N1 and amplitude of P1-N1 complex were analysed. The different patterns of cVEMPs recorded from individuals with unilateral sensorineural hearing loss in normal ear are shown in figure 4.6.

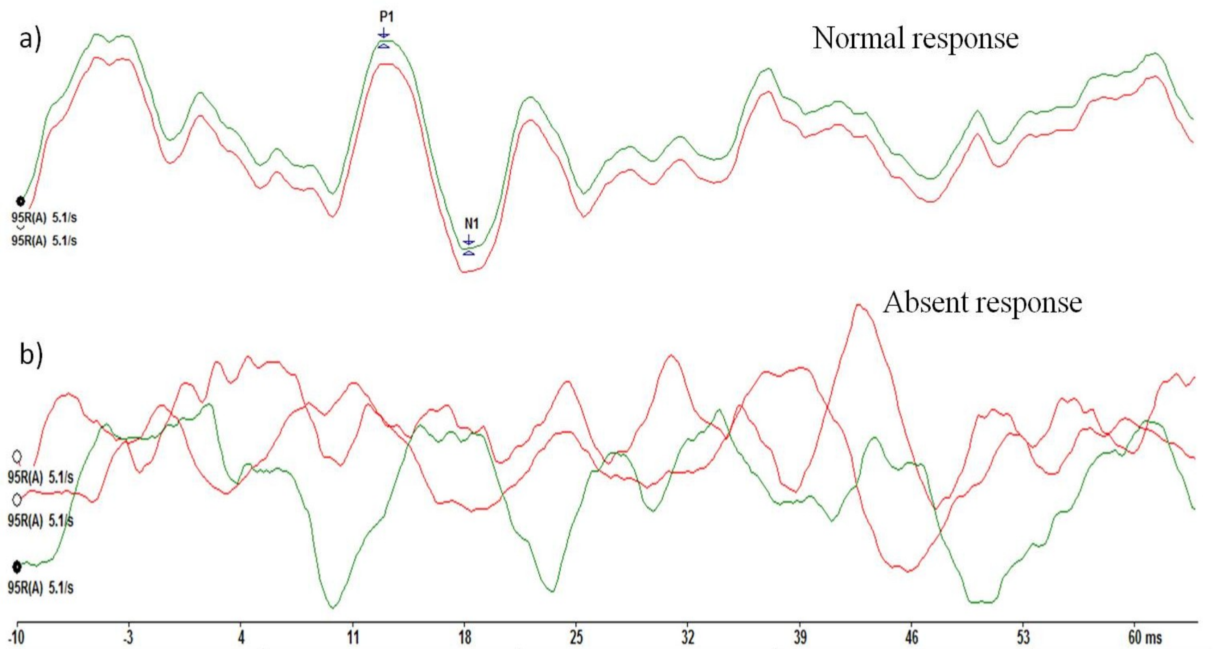

Figure 4.6 cVEMP responses to 500 Hz tone burst at 95 dBnHL stimuli in individuals with unilateral sensorineural hearing loss of normal ear (a) Normal cVEMPs response (b) Absent cVEMPs response.

Out of 10 ears, 5 ears had absence of cVEMPs responses (50%), and 5 had normal responses (50%). The mean, standard deviation and range of absolute latency of waves P1, and N1 and amplitude of P1-N1 complex amplitude at 95dBHL are given in Table 4.5.

Table 4.5

The mean, standard deviation and range of absolute latency of waves P1, and N1 and amplitude of P1-N1 complex at 95dBHL

Parameters	Mean	Standard deviation	Range
P1 latency (ms)	13.69	1.21	12.80 - 15.80
N1 latency (ms)	19.62	1.00	18.40 – 21.00
Amplitude of P1-N1 complex (µV)	23.98	12.62	5.45 – 35.84

4.5.2 Ocular vestibular evoked myogenic potentials test results in normal ear

Latency of N1, latency of P1 & latency of N2 and amplitude of N1-P1 & P1-N2 complex was analysed. The results of oVEMPs for one participant of unilateral sensorineural hearing loss in affected ear is shown in figure 4.7

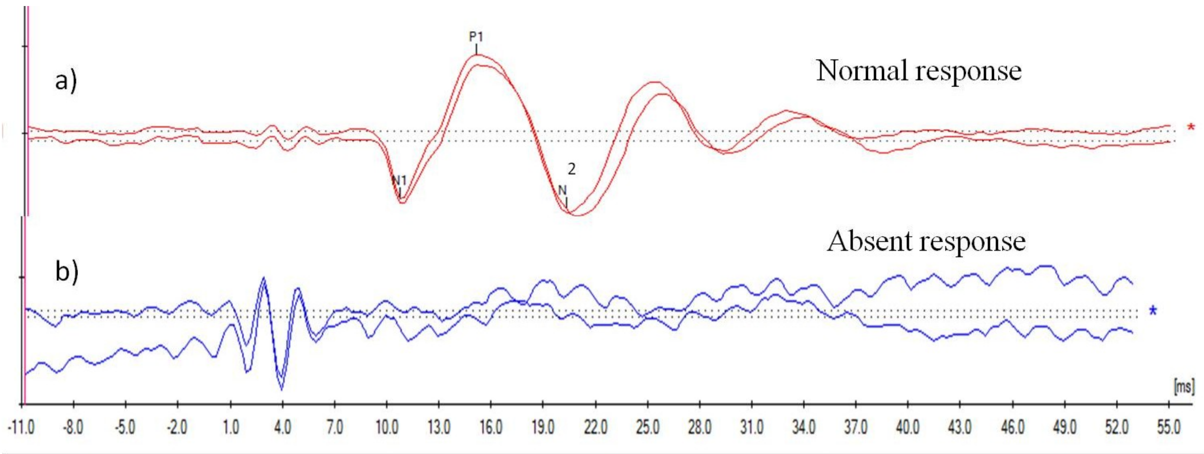

Figure 4.7 oVEMPs responses to 500HZ tone burst at 95 dBnHL stimuli in an individual with unilateral hearing loss of normal ear, a) normal oVEMP response, b) absent oVEMP response.

Out of 10 ears 8 ears had absence of oVEMPs responses (80%) and 2 had normal responses (20%). Out of the normal responses, for one subject the latency of N1 was 10.45ms, P1 was 17.20ms & for N2 was 22.95ms. Amplitude of N1-P1 complex was 6.75 µV & for P1-N2 was 5.75 µV. For second subject the latency was 9.95ms, for P1 was 15.20ms & for N2 was 19.95ms. Amplitude of N1-P1 complex was 6.75 µV & for P1-N2 was 4.00 µV.

4.5.3 Caloric Test results in normal ear

Out of 10 ears with unilateral sensorineural hearing loss, Caloric test results showed hypoactivity in 8 ears (80%) and 2 ears (20%) showed normal response to caloric stimulation.

4.6 Association of Caloric test, cVEMPs and oVEMPs results in subjects with unilateral hearing loss in normal ear

The figure 4.8 shows the presence and absence of cVEMPs, oVEMPs and caloric test results in individual with sensorineural hearing loss in normal ears.

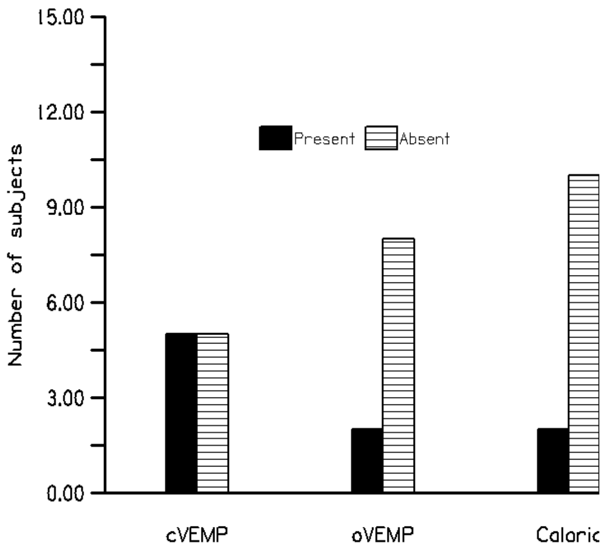

Figure 4.8 shows the presence and absence of cVEMPs, oVEMPs and caloric test results in individual with sensorineural hearing loss in normal ears.

As, the caloric test results, cVEMPs results & oVEMPs test results were affected differentially in different participants Chi-square test was done to find out if any association exists between caloric, cVEMPs and oVEMPs test results. The details of Chi-square test are given in table 4.6.

Table 4.6

Association of caloric test, cVEMPs and oVEMPs results in subjects with unilateral sensorineural hearing loss in normal ear

Test		**oVEMPs**			**cVEMPs**		
		Normal	**Abnormal**	**Total**	**Normal**	**Abnormal**	**Total**
Caloric test	Normal	0	2	2	0	2	2
	Abnormal	2	6	8	5	3	10
	Total	2	8	10	5	5	10
cVEMPs	Normal	0	5	5			
	Abnormal	2	3	5			
	Total	2	8	10			

Chi-square test results revealed no association between presence and absence of cVEMP and oVEMP responses (p= 1.00). No association between caloric and cVEMP (p=1.00) and also no association between caloric and oVEMP (p=0.42) of subjects with unilateral sensorineural hearing loss in normal ear was obtained.

4.7 Association between duration of the hearing loss with vestibular test results in normal ear

As, the caloric test results, cVEMPs results & oVEMPs test results were affected differentially in different participants Chi-square test was done to find out if any association exists between duration of hearing loss and caloric, cVEMPs & oVEMPs test results. The details of Chi-square test are given in table 4.7.

Table 4.7

Association of vestibular tests with the duration in subjects with unilateral sensorineural hearing loss in normal ear

S.NO.	Duration (in months)	cVEMP	oVEMP	Caloric
1	12	Present	Absent	Absent
2	1	Absent	Absent	Absent
3	24	Present	Absent	Present
4	36	Absent	Absent	Absent
5	12	Absent	Present	Absent
6	432	Present	Present	Absent
7	8	Absent	Absent	Present
8	240	Present	Absent	Absent
9	24	Absent	Absent	Absent
10	36	Present	Absent	Absent

Chi-square test results revealed no association between duration of hearing loss and cVEMP (p=0.67), no association between duration of hearing loss and oVEMP (p=0.33) and also no association between duration of hearing loss and caloric results (p=0.33) in contralateral side in subjects with unilateral sensorineural hearing loss.

Discussion for contralateral ear findings:

The absence of cVEMP, OVEMP and calorics responses in the contralateral ear may be attributed to the central bilateral interaction which generally reduces the better ear response for balancing (Rauch et al, 2004). Also, it may be possible that the abnormal finding in the contralateral ear is an indication of the vestibular system involvement in the contralateral ear. However the puretone thresholds are normal in the other ear. One may ask a question that the cochlear and vestibular system are almost similar, there should have been some amount of hearing loss in the contralateral ear. It may be possible that the sudden sensorineural hearing loss might be affecting the vestibular system differentially compared to the cochlear system, and hence the responses are absent in contralateral ears also in most of the subjects or the absence of responses could be due the combination of differential damage and also due to increased VOR gain.

4.8 Association between vestibular symptoms and different vestibular test findings in individuals with unilateral sensorineural hearing loss

Since the aim of the study was to compare the findings in unilateral sensorineural hearing loss. The signs and symptoms of these cases were correlated with respect to the findings of the affected ear which is shown in table 4.8.

Table 4.8

Association of caloric test, cVEMPs and oVEMPs with the vestibular symptoms present in subjects with unilateral sensorineural hearing loss

Test Results/ Vestibular Symptoms	cVEMP		oVEMP		Caloric	
	Present	Absent	Present	Absent	Present	Absent
Spinning Sensation	1	5	2	5	0	5
Imbalance	0	1	0	0	0	1
Blacking out	0	1	0	1	0	1
Headache	1	4	2	4	0	4
Nausea or vomiting	0	3	0	3	0	3
Tinnitus	0	5	1	5	0	5

In the present study variable amount of association was obtained between the sign and symptoms exhibited by the clients and the different test results. Based on these sign and symptoms exhibited by the client, and the test results obtained in the present study one can narrow down the site lesion in the diagnosis of peripheral vestibular disorders. For example, the participant has a blackout only if all the three tests results are affected i.e. there is an absence of cVEMP, oVEMP and caloric responses. Similarly, an imbalance is seen if the cVEMP and caloric test results are affected.

To summarise, the cVEMP, oVEMP and calorics test results were absent in most of the participants with unilateral sudden sensorineural hearing loss. Further no association could be observe between duration of the disease and the vestibular test finding or degree of hearing loss and vestibular test findings. Also, in the contralateral ears of the individuals with unilateral sudden sensorineural hearing loss had significant absence of vestibular test results.

CHAPTER – 5

Summary and Conclusion

Unilateral sensorineural hearing loss can affect individuals at any period of their life span, can remain static and/or can be progressive, and can vary in severity ranges from mild to profound. Most of the subjects have an idiopathic etiology. Etiologies of unilateral sensorineural hearing loss like neoplasms, stroke, demyelinating and autoimmune diseases, infection, perilymphatic fistula, and Meniere's disease, need to be excluded. However, there is a minor group of subjects who stays with unilateral hearing impairment, sometimes involves vestibular system also (Voelker & Chole, 2010). Anatomical proximity of the cochlea and the vestibular system and chances of dent caused by the same pathogenic factor implies that sensorineural hearing loss may be coexist with vertigo and dizziness. Hence a minor group of subjects with unilateral sensorineural hearing loss may have vestibular symptoms (Voelker & Chole, 2010).

Unilateral sensorineural hearing loss may affect the vestibular system, which can lead to vestibular dysfunction of the reflex responses of the vestibular system. There are three primary reflexes which are vestibulo-ocular, vestibulo-spinal, and vestibulo-collic reflexes. These reflexes are playing a major role in maintaining balance. So, assessment of vestibular functioning should involve the measuring of integrity of different vestibular reflex pathways. Caloric test mainly assesses the functioning of vestibulo-ocular reflex from the horizontal semicircular canal through superior branch of the vestibular nerve. Cervical vestibular evoked myogenic potential (cVEMPs) is commonly used in the vestibular assessment which assesses the functioning of saccule and inferior vestibular nerve. Ocular vestibular evoked myogenic potential (oVEMPs) is the new variant of the vestibular evoked myogenic potentials which predominantly assesses the functioning of otolith organs mainly utricle and superior branch of the vestibular nerve (Jacobson et al., 2011).

Hence combination of caloric test, cVEMPs and oVEMPs may provide valuable information regarding the pathways involved in different vestibular dysfunction. So the present study was aimed to assess the different vestibular pathways (Semicircular canal ocular reflex pathway, Vestibulo-collic reflex pathway & Otolith-ocular reflex pathway) in subjects with unilateral sensorineural hearing loss.

To achieve the aim of the study total 10 male participants with unilateral sensorineural hearing loss aged between 17 to 55 years were taken for the study. Caloric test, cVEMPs and oVEMPs were recorded for all the participants in the present study and the following analysis was made.

- For caloric test, the hyperactivity and hypoactivity of the responses was analysed with the help of Claussen's Butterfly chart. To plot the results in butterfly chart the culmination frequency was calculated. This culmination frequency was calculated in all 4 simulation conditions.
- For cVEMP responses, latency and amplitude of P1, N1 and complex of P1 – N1 was analysed for each subject.
- For oVEMP, latency and amplitude of N1, P1 peaks and amplitude complex of N1-P1 & P1- N2 was analysed for each subject.

To analyze the data following statistics were done

1) Descriptive statistics was done to find out the mean and standard deviation of P1 and N1 latency, amplitude of P1-N1 complex in cVEMPs in normal side of the subjects in control group.

2) Chi-square test to find association of caloric test, cVEMPs and oVEMPs in affected and normal ear of individuals with unilateral sensorineural hearing loss.

Results of the study revealed the following

1. In the affected side, out of 10 ears (10 participants) with unilateral sensorineural hearing loss, 9 ears had absence of cVEMPs responses (90%). In oVEMPs recordings 8 affected ears showed absent responses (80%). The caloric test results showed hypo activity in 10 affected ears (100%).
2. There was association between presence and absence of cVEMP and oVEMP responses. Association cannot be found between the caloric & cVEMP and caloric & oVEMP as the result of caloric test were constantly absent in all the ears.
3. In the affected side, no association was found between duration of hearing loss and cVEMP and also there was no association between duration of hearing loss and oVEMP.
4. In the affected side, no association was found between degree of hearing loss and cVEMP and also there was no association between degree of hearing loss and oVEMP.
5. In the normal side, out of 10 ears (10 participants) with unilateral sensorineural hearing loss in normal side, 5 ears had absence of cVEMPs responses (50%). In oVEMPs recordings 8 affected ears showed absent responses (80%). The caloric test results showed hypo activity in 8 affected ears (80%). There was no association between presence and absence of cVEMP and oVEMP responses. There was no association

between caloric and cVEMP and also no association between caloric and oVEMP.

6. In the normal side, no association was found between duration of hearing loss and cVEMP, there was no association between duration of hearing loss and oVEMP and also there was no association between duration of hearing loss and caloric results.

Conclusions

Caloric test, cVEMPs and oVEMPs mainly assesses the functioning of semi circular canal ocular reflex pathway, sacculo-collic pathway and utriculo-ocular reflex pathway respectively. In vestibular dysfunction, one or more reflex pathways are affected. Since the above 3 tests assess the functioning of 3 different pathways, the combination of the caloric, oVEMP, and cVEMP tests should be administer to find site of lesion in the vestibular labyrinth.

Implications of the study:

- This study provides information regarding the diagnostic significance of combination of ENG, cVEMPs, and oVEMPs in individuals with unilateral sensorineural hearing loss.
- This study provides basis for selection of the different kinds of vestibular rehabilitation in individuals with dizziness based on the affected reflex pathways.
- The study will help in identifying the exact site of lesion in subjects with unilateral sensorineural hearing loss.

Future directions:

- The present study has been done with a smaller group of participants. So, the study can be replicated with the larger group.
- The study can be replicated in idiopathic sudden sensorineural hearing loss.
- Studying the recovery patterns of functioning of different vestibular reflex pathways in individuals with unilateral sensorineural hearing loss using combination of caloric test, cVEMPs and oVEMPs.

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