UTILITY OF VESTIBULAR EVOKED MYOGENIC POTENTIALS IN THE DIFFERENTIAL DIAGNOSIS OF SUSPECTED MENIERE'S DISEASE AND BENIGN PAROXYSMAL POSITIONAL VERTIGO

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Certificate

This is to certify that this dissertation entitled "Utility of Vestibular Evoked Myogenic Potentials in the Differential Diagnosis of Suspected Meniere's Disease and Benign Paroxysmal Positional Vertigo" is a bonafide work in part of fulfillment for the degree of Master of Science (Audiology) of the student Registration no: 07AUD020. This has been carried under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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This is to certify that this dissertation entitled "Utility of Vestibular Evoked Myogenic Potentials in the Differential Diagnosis of Suspected Meniere's Disease and Benign Paroxysmal Positional Vertigo" has been prepared under my supervision & guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

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Declaration

This is to certify that this master's dissertation entitled "Utility of Vestibular Evoked Myogenic Potentials in the Differential Diagnosis of Suspected Meniere's Disease and Benign Paroxysmal Positional Vertigo" is the result of my own study and has not been submitted earlier to any other university for the award of any degree or diploma.

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1. Introduction

Vestibular evoked myogenic potential (VEMP) is an electromyographic response to loud auditory stimuli that is recorded in the sternocleidomastoid muscle during tonic contraction. It is used as a clinical test for the vestibular system by providing information on otolith function and the functional integrity of the inferior vestibular nerve, (Zhou & Cox, 2004).

Vestibular neuritis, benign paroxysmal positional vertigo (BPPV), and Meniere's disease (MD) are the most common diseases that cause peripheral vertigo. The development of peripheral vertigo can be associated with the saccule or inferior vestibular nerve, which are pathways for VEMP. Patients with vestibular neuritis show unilateral peripheral vestibular dysfunction mainly in the superior vestibular nerve (Fetter & Dichgans, 1996). Recent studies have also demonstrated that some patients have a dysfunction in the inferior vestibular nerve (Halmagyi, Aw, Karlberg, Curthoys, & Todd, 2001).

Heide, Freitag, Wollenberg, Schimrigk, and Dillmann (1999) reviewed VEMP response in three BPPV patients, in which all the patients had a normal recorded VEMP response. However, a more recent study on BPPV patients indicated that 30% of the patients showed abnormal VEMP responses (Akkuzu, Akkuzu & Ozluoglu, 2006). Furthermore, as Meniere's disease is associated with a pathologic change in the saccule, VEMP testing could provide information about involvement of the saccule in peripheral vertigo.

Matsuzaki and Murofushi, (2001) reported bilateral absence of VEMPs in cases with bilateral vestibulopathy. Ochi, Ohashi, and Watanabe, (2003) reported abnormal VEMPs and its recovery in patients with ipsilateral vestibular neuritis.

Vestibular-dependent short-latency electromyographic (EMG) responses to intense sound were initially recorded from the posterior neck muscles inserting at the inion, (Bickford, Jacobson & Cody, 1964). VEMPs are now recorded using symmetric sites over the sternocleidomastoid

muscles (SCMs), (Colebatch, Halmagyi, & Skuse, 1994). The response consists of an initial positivity or inhibition (p13) followed by a negativity or excitation (n23) (figureure 1). Later components (n34, p44) have a lower stimulus threshold and are non-vestibular (probably cochlear) in origin.

The short-onset latency of the VEMP (about eight milliseconds) indicates that it is likely to be mediated by an oligosynaptic pathway, possibly disynaptic and consisting of primary vestibular afferents projecting to the vestibular nuclear complex and thence via the medial vestibulospinal tract to the accessory nucleus, (Welgampola & Colebatch, 2005).

The VEMP arises from modulation of background EMG activity and differs from neural potentials in that it requires tonic contraction of the muscle. It is best observed in averaged unrectified EMG. In single-unit EMG recordings, intense clicks are followed by a 2- to 6-millisecond period of inhibition between 8 and 20 milliseconds following the stimulus that coincides with the surface positivity (Colebatch & Rothwell, 2004).

A morphologic and physiologic study in experimental animals confirms that intense sound selectively activates otolith afferents, (Murofushi, Curthoys, & Gilchrist, 1996). Stimulation of the saccular nerve in cats results in inhibitory postsynaptic potentials in the ipsilateral SCM motor neurons, which travel in the medial vestibulospinal tract, (Uchino, Sato, & Sasaki, 1997; Kushiro, Zakir, Ogawa, Sato, & Uchino, 1999) with only weak effects on the contralateral neurons. Utricular nerve stimulation, in contrast, evokes excitatory postsynaptic potentials in about two-thirds of contralateral SCM neurons, (Uchino, Sato, & Sasaki, 1997). Thus, the predominantly ipsilateral, inhibitory SCM responses (e.g., click VEMPs) are likely to represent saccular activation, and prominent crossed responses (observed in direct current [DC] – and tap-evoked VEMPs) may indicate utricular stimulation.

By using the vestibular apparatus, VEMP has been used to assess not only the inferior vestibular nerve, also the activity of extra ocular muscles using Ocular-VEMP (Iwasaki et al, 2007), the crossed and uncrossed pathways of spinal cord (Rudisill, & Hain, 2008), and vestibular evoked potentials recorded from human masseter muscles and from scalp electrodes are the new techniques whose characteristics are still being explored.

NEED FOR THE STUDY

Vestibular-evoked myogenic potential testing may provide additional information about the vestibular system and allow site of lesion testing (e.g. saccule and inferior vestibular nerve) in patients of all ages. Its role has yet to be defined in the diagnosis and treatment of common vestibular disorders, including Meniere's disease, vestibular neuronitis, labyrinthitis, and other diseases. Further, research is needed to support its clinical usefulness in patients with balance disorders, to optimize patient selection, and to establish its cost effectiveness (Honaker, & Samy, 2007).

New applications for vestibular evoked myogenic potential is needed in diagnosis and monitoring of neurotologic disease, and in shedding light on inner ear diseases by mapping anatomic sites of involvement. The most informative work is still in the areas of Benign paroxysmal positional vertigo and in Meniere's disease. Also, many aspects of vestibular evoked myogenic potential and its use have not yet been adequately studied or described. It holds great promise for diagnosing and monitoring Meniere's disease and Benign paroxysmal positional vertigo. The methods, equipment, and applications for vestibular evoked myogenic potential testing are not yet standardized (Rauch, 2006).

VEMP is a testing method that evaluates the saccule and the inferior vestibular nerve in the peripheral vestibular system. The test is easy, noninvasive and causes minimal patient

discomfort. VEMP has been used as a complimentary test with the conventional vestibular function test in patients with peripheral vertigo. The main parameters of the VEMP responses used in clinical diagnosis are p13 and n23 latencies and the peak to peak amplitude. Recently, interaural amplitude difference ratio (IADR) has been recognized as one of the valuable clinical tools in the assessing individuals with vestibular dysfunction (Young, Huang & Cheng, 2003). Any conditions affecting the normal physiology of the vestibular system will have a significant effect on its evoked potentials. The most common conditions affecting the vestibular system are Meniere's disease and benign paroxysmal positional vertigo. IADR might throw some important information in identification of BPPV and MD. Thus, the current study has been taken up, with the following aim.

AIM OF THE STUDY

- To identify the pattern of VEMP responses in individuals with normal auditory and vestibular functioning, individuals with MD and in individuals with BPPV.
- To check for ear wise differences for the three groups.
- To compare the parameters of VEMP responses between the groups.
- To compare the interaural amplitude difference ratio (IADR) across the groups.
- To check for ear effect in VEMP responses for individuals with unilateral MD.

2. Review of literature

Clinical tools for diagnosing vestibular disorders caused by semicircular canal dysfunction are readily accessible, while tests sensitive to otolith disorders are scarce. During the past few decades, there have been studies on vestibular evoked myogenic potentials (VEMP's) in animals and humans. It is thought that VEMP's have a vestibular origin.

From the evolutionary point of view, the cochlear portion of the membranous labyrinth is considered a late development in man (Ferber-Viart, Dubreuil, & Duclaux, 1999; Todd, Cody, & Banks, 2000). In lower species such as fish, the saccule often acts as an acoustic-sensitive organ in the absence of a cochlea (Fay & Popper, 1980; Popper, Platt, & Saidal, 1982). The acoustic sensitivity of vestibular end organs, such as the saccule, has also been reported in mammals (Cazals, Aran, & Erre, 1983; McCue & Guinan, 1995; Young, Fernandez, & Goldberg, 1977). For humans, some authors speculate that the saccule has retained an ancestral acoustic sensitivity, although it has a specific role in balance (McCue & Guinan, 1997; Todd, Cody, & Banks, 2000). Anatomically, the saccule is located directly beneath the footplate of the stapes (Rauch, Merchant, & Thedinger, 1989), aligning it for stimulation by loud sounds. It should be noted, however, that sound levels needed to elicit the VEMP are sufficiently high that it is difficult to determine specifically whether the response is vestigial acoustic or due to endolymph compression producing a mechanical response from the vestibular mechanoreceptor (hair cells) (Zhou & Cox, 2004).

In animal experiments, it is possible to observe sound elicited responses from the saccule through direct recording of neurogenic responses. This approach, however, is ethically difficult for human studies with sound-evoked responses. As an alternative, researchers have focused on the possibility of recording muscular responses, which are evoked by acoustic stimuli and likely originate from the vestibular organs, such as the saccule (Zhou & Cox, 2004).

When Geisler, Frishkopf, and Rosenblith (1958) recorded short latency responses to auditory clicks at the inion, these responses were thought to be of cortical origin. Bickford, Jacobson, and Cody (1964) described the characteristics of averaged inion responses to clicks and concluded the responses were vestibular in origin. From their observation of 30 normal participants, they found that the inion responses were greatly affected by alterations in the tension of neck muscles and thus were “myogenic” in nature. Their study of patients with various

auditory/ vestibular system lesions indicated that the responses were of vestibular origin rather than cochlear. Later studies by Cody and Bickford (1969) and Townsend and Cody (1971) provided further evidence suggesting that these responses arose from activation of the vestibular end organ, specifically the saccule.

In spite of the above research, recording sound-evoked inion responses was not applied to clinical use primarily due to the responses' inconsistency. In 1994, Colebatch, Halmagyi and Skuse established a reliable procedure to record the myogenic potentials evoked by clicks. These authors revised previous recording procedures by putting surface electrodes on the sternocleidomastoid (SCM) muscles, rather than placing them at the inion. With the high quality of electromyography recording techniques, they documented the responses to be repeatable. These responses were described as "click evoked vestibulo-collic responses." Other researchers have labeled these responses "vestibular evoked myogenic potentials" because they are muscular potentials evoked by stimulation of the vestibular end organ (Robertson & Ireland, 1995; Murofushi, Halmagyi, Yavor & Colebatch, 1996; Murofushi, Matsuzaki & Mizuno, 1998).

Normal VEMP responses are characterized by biphasic (positive - negative) waves. In a majority of studies, the peaks and troughs are usually labeled with the mean latency in milliseconds preceded by the lowercase letters "p" (for positive) or "n" (for negative), as proposed by Yoshie and Okudaira (1969) to distinguish them from neurally generated evoked potentials. The first positive – negative complex is often labeled as p13–n23. This early response has been present in a majority of normal participants as cited in published studies (Versino, Colnaghi, Callieco, & Cosi, 2001; Wang & Young, 2003; Basta, Todt, & Ernst, 2005; Maes et al., 2008). Additional potentials such as n34–p44 may follow but are not present in all normal participants. Colebatch, Halmagyi, and Skuse (1994) reported that the second wave complex (n34–p44) was absent in 40% of their participants, while Robertson and Ireland (1995) found the second wave complex (n34–p44) to be present in 68% of their participants.

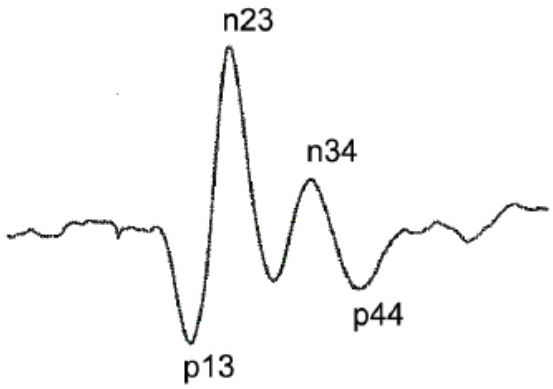

Figure 2.1: The VEMP response consists of an early biphasic positive-negative component that occurs at 13 ms to 23 ms post stimulus (p13-n23). The later components occur at 34 and 44 ms post stimulus (n34-p44), (Damen, 2007).

2.1 Generators and Neural Pathway of VEMP

2.1.1Receptor

The early study by Bickford, Jacobson, & Cody, (1964) provided an initial outlook regarding the origin and neural pathway of VEMPs. They ruled out the response as being a part of the startle or voluntary system. Instead, they proposed a short reflex arc. Because the response was present in patients with sensorineural hearing loss and absent in those with loss of vestibular function, they concluded that the vestibular end organs were the receptors, not the cochlea. Furthermore, the response was preserved in patients with semicircular canal ablation due to streptomycin toxicity and in patients with benign paroxysmal positional vertigo (BPPV), but it was absent in patients with advanced Meniere's disease (MD) and in MD patients having undergone a Cody tack procedure (cochleosacculotomy). Based on these findings, Townsend and Cody (1971) suggested that the response was mediated by the saccule.

Cazals, Aran, Erre, Guilhaume, and Aurousseau (1983) reported that acoustically evoked responses could be recorded in guinea pigs with total cochlear, ampullar, and utricular destruction but undamaged saccular sensory epithelium. In a study on human participants,

Sheykholeslami and Kaga (2002) suggested anatomical evidence of the saccule being the receptor of VEMPs. Their results found VEMPs present in patients with gross abnormality of the bony labyrinth including the cochlea and semicircular canals and with what appeared to be a preserved vestibule as noted by computerized tomography (CT).

2.1.2Afferent Pathways

In a study done by Townsend and Cody (1971), VEMPs were absent in a patient who had a vestibular nerve section and in a second patient who had vestibular neuritis. Recent reports have suggested that VEMPs are mediated through the vestibular nerve. Colebatch and Halmagyi (1992) investigated VEMPs from one patient before and after selective vestibular nerve section. They found that the p13–n23 wave was abolished after the surgery. Later, Colebatch, Halmagyi, and Skuse (1994) and Halmagyi and Colebatch (1995) studied VEMPs in patients who had selective vestibular nerve section and vestibular neuritis. They reported no VEMPs from the surgical side in all patients who had the selective vestibular nerve section. In the patients who had vestibular neuritis, VEMPs were either abolished or reduced in amplitude. Robertson and Ireland (1995) suggested that the VEMP p13–n13 originates from the saccule and may travel along the inferior vestibular nerve to the vestibular nuclei.

2.1.3Efferent Pathways

Bickford, Jacobson, and Cody (1964) suggested that the vestibulospinal tract could be the efferent pathway of sound-evoked myogenic potentials. The vestibular nuclei that receive afferent fibers from the saccule have a major descending connection to spinal motor neurons. The lateral vestibulospinal tract (LVST) and the medial vestibulospinal track (MVST) that originates from Deiter's cells were considered as possible efferent pathways for the SCM. Both the LVST and MVST were found projecting to the anterior horn cells (motor neurons) of the cervical cord, which control all the neck muscles including the SCM muscles. Colebatch,

Halmagyi, and Skuse (1994) proposed the LVST to be the efferent pathway of VEMPs based on existing evidence from published animal studies.

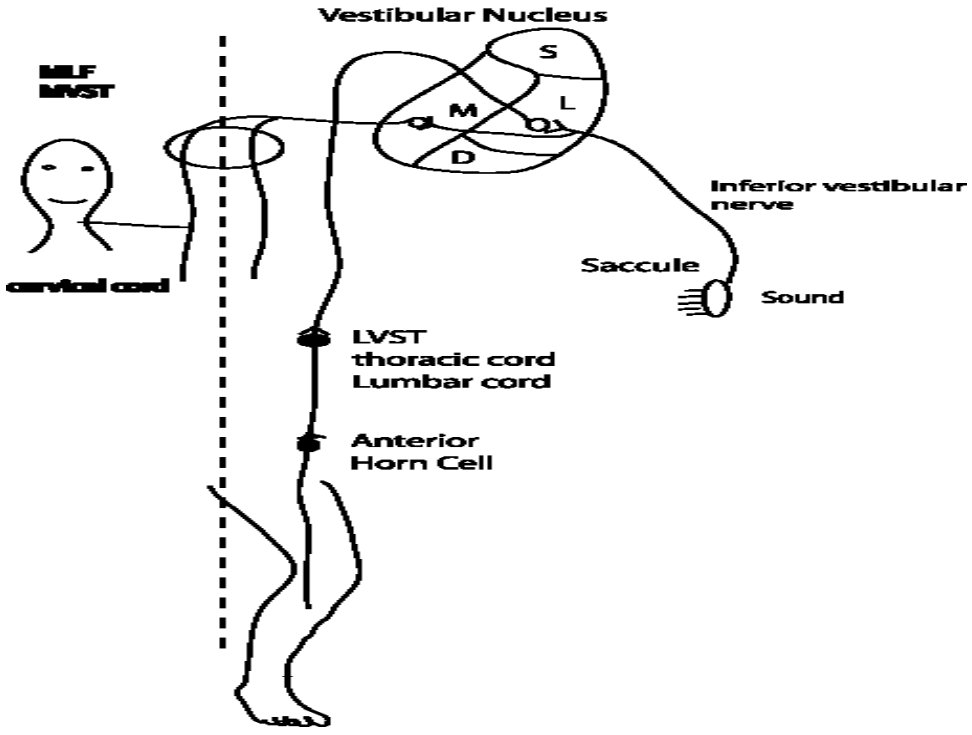

Figure 2.2: VEMP neural pathway. Sound stimulates the saccule, which activates the inferior vestibular nerve, lateral vestibular nucleus, medial vestibulospinal tract ipsilaterally, and then the sternocleidomastoid muscle in the neck.

Controversial studies

Halmagyi and Colebatch (1995) reported that a vestibular nerve section led to abolition of the p13–n23 response to ipsilateral stimulation on the surgical side but the response was unchanged when stimuli were presented to the contralateral ear. This finding would put in doubt the idea that VEMPs are a pure ipsilateral phenomenon.

Since sectioning of the vestibular nerve may not always lead to abolition of VEMPs, it is reasonable to believe that the afferent pathway may be more complicated than currently understood. There is some anatomical and histological evidence that cochlear and vestibular fibers are overlapping (Natout, Terr, Linthicum, & House, 1987). Therefore, the existence of VEMPs after a vestibular nerve section could be due to vestibular fibers travelling through the cochlear nerve.

2.2 Factors affecting VEMP responses

The variations in VEMP amplitudes are mostly reported. It can vary from a few micro volts to several hundred micro volts, depending on the muscle tension and the intensity of the stimuli (Colebatch, Halmagyi, & Skuse, 1994; Pyykko, Aalto, Gronfors, Starck, & Ishizaki, 1995; Li, Houlden, & Tomlinson, 1999; Wu & Murofushi, 1999; Wu, Young, & Murofushi, 1999; Ochi, Ohashi, & Nishino, 2001; Versino et al, 2001; Cheng & Murofushi, 2001a, 2001b). In contrast, the latency of the response is usually less varied and does not differ significantly from the right to left side. The following factors have been reported as contributors to uncertainty of VEMP waveforms.

***Electrode montage*:** Electrode montage is reported to have significant effect on VEMP response. In the studies done by Bickford, Jacobson, and Cody (1964) and Cody and Bickford (1969), the active electrode was placed on the scalp at the inion, the reference electrode was placed on the nose or earlobe, and the ground electrode was placed on the forehead. With this configuration, they could record VEMP from 90% of normal subjects. Colebatch, Halmagyi, and Skuse (1994) showed that the p13–n23 was present in all normal participants using Sternocleidomastoid (SCM) muscles as the recording site. In their study, the active recording electrodes were placed on the upper third of the muscle belly, and reference electrodes were placed on the muscle tendon just above the sternum. The authors explained that these sites were preferable to the inion to allow greater certainty as to the specific muscles likely to be generating any responses

seen and avoid the uncertainties inevitably associated with use of a midline recording site when investigating the effects of unilateral stimuli. This method of recording is called as 'belly-tendon' recording principle. Most subsequent researchers have adopted this electrode configuration in their studies (Akin, Murnane, & Proffitt, 2003; Cheng & Murofushi, 2001a).

In addition to SCM muscles, trapezius (TRP) muscles have been used as recording sites and the authors conclude that the latencies of responses obtained on SCM were significantly shorter, and amplitudes lower, than those obtained on TRP. Binaural stimulation resulted in responses of greater amplitude compared to monaural (Ferber-Viart, Duclaux, Colleaux, & Dubreuil, 1997). Studies revealed similar findings to those recorded at SCM muscle locations. Other remote recording sites such as arms and legs have also been reported, were the latencies of VEMP peaks are prolonged than the neck responses (Li, Houlden, & Tomlinson, 1999). Even, extra-ocular muscles were stimulated and VEMP responses were recorded using air-conducted 500 Hz tone burst and are best recorded contralaterally on upgaze (Chihara, Ito, Sugasawa, & Shin, 2007).

***Stimuli*:** Both clicks and tone bursts can be used as stimuli presented via earphones, monaurally or binaurally. It is generally agreed that a 90 dBnHL click is adequate to evoke the responses. A slow repetition rate such as 5–7/s is usually preferred with averaging fewer than 500 sweeps for each run (Zhou & Cox, 2004). Colebatch, Halmagyi, and Skuse (1994) reported that the amplitude of the response increases with increasing stimulus intensity. Other studies confirmed the linear relationship between the amplitude of the response and the intensity of the stimulus (Cheng & Murofushi, 2001a; Cheng & Murofushi, 2001b; Akin, Murnane, & Proffitt, 2003). Welgampola and Colebatch (2001) reported that tone-burst–evoked myogenic responses were similar to click-evoked responses but required lower stimulus intensities. Their study showed a "frequency tuning" feature with the largest amplitude at either 500 Hz or 1000 Hz. Todd, Cody, & Banks

(2000) confirmed frequency tuning in VEMPs; however, they found that the maximum response was at frequencies between 300 and 350 Hz.

Similar to air-conducted clicks and tone bursts, bone conducted clicks and tone bursts can also elicit VEMPs from the SCM muscles (Sheykholeslami, Murofushi, Kermany, & Kaga, 2000). Skull taps and bone-conducted tones are stimuli that bypass the middle ear conductive apparatus and can evoke VEMPs despite conductive hearing loss. A forehead tap, delivered at Fpz (International 10 –20 System) via a tendon hammer, evokes a vestibular-dependent short-latency p1n1 response in both SCMs (Halmagyi, Yavor , & Colebatch, 1995). The tap also evokes a second negativity ("n2"), which can sometimes be difficult to separate from n1 and thus precludes unambiguous analysis in some normal subjects. In unilateral vestibular deafferentation, a prominent crossed response is seen on the SCM ipsilateral to the lesion, representing crossed excitation from the intact side.

***Muscle tension*:** Bickford, Jacobson, and Cody (1964) noticed that muscle tension was involved in the presence of the response. Increased tension in the neck muscle produced increase in amplitude, while the intensity of stimuli remained unchanged. Studies have described specifically the relationship between muscle tension and the amplitude of VEMPs. Colebatch, Halmagyi, and Skuse (1994) monitored electromyographic activity with an oscilloscope and quantified the activity with mathematical analysis. In all of their participants, there was a linear relationship between the amplitude of the response and the mean level of electromyography activity. This finding was confirmed by later studies and is considered as one of the unique features of VEMPs. EMG target levels ranging from 30 μV to 50 μV are suggested for clinical application of the VEMP (Akin, Murnane, Panus, Caruthers, Wilkinson, & Proffitt, 2004).

Response laterality: Response laterality also contributes in affecting the VEMP responses. In the early studies by Bickford, Jacobson, and Cody (1964) and Townsend and Cody (1971), symmetric responses from both sides were reported. In contrast, Colebatch, Halmagyi, and Skuse (1994) reported that the response was always larger on the ipsilateral SCM muscles when monaural stimuli were presented. Robertson and Ireland (1995) also studied the laterality of VEMPs. They obtained symmetric responses from SCM muscles to clicks presented unilaterally to 7 normal participants. Ferber-Viart et al. (1997) demonstrated that responses tended to be greater in SCM muscles contralateral to the side of stimulation. Ferber-Viart et al. (1997) reported that there was no significant left–right difference in amplitude under binaural stimulation, while binaural stimulation tended to produce greater amplitude when compared to monaural stimulation. Wang and Young (2003) investigated VEMPs using binaural and monaural stimulation. They found no significant difference in VEMPs when looking at the two stimulation modes and suggested that simultaneous bilateral stimulation might be a better option when testing old or disabled patients.

Other Factors

Bickford, Jacobson, and Cody (1964) demonstrated that VEMPs were myogenic in origin. They further stated that this response was not a part of the startle system. First, the two responses were found to be different in latency. Startling usually appears at 50 ms in response to a loud sound, while VEMPs are short latency (less than 20 ms) responses. Secondly, VEMPs can be driven at fairly high rates of repetition, while the startle reflex is characterized by rapid habituation and a prolonged refractory period. In additional tests, they found that voluntary movement of the head to a sound produces a reaction time of 100 ms. Thus, VEMPs are not considered to be voluntary in nature either.

2.3 Clinical Applications of VEMPs

Compared to the auditory system, the vestibular system is more complex and less understood. Furthermore, few reliable evaluation procedures are available. Current electrophysiological evaluation of the vestibular system, such as ENG and computerized dynamic posturography, do not assess all functional structures and pathways. Reliable clinical procedures to evaluate the function of otolith organs (the saccule and the utricle) have not been available for clinical use until recently (Halmagyi & Curthoys, 1999).

Complete assessment of vestibular function is an important measurement in neurology, otology, and audiology. Typical tests used in the electronystagmography (ENG) battery only assess the integrity of lateral semicircular canals and the superior vestibular nerve. By adding VEMP measurements, the clinician may have the capability of revealing disorders in the saccule and/or inferior vestibular nerve (Zhou & Cox, 2004).

Since Colebatch, Halmagyi, and Skuse (1994) revised the recording procedure, VEMP testing has become attractive for clinical use, especially for the diagnosis of peripheral vestibular pathologies. The VEMPs are suitable for clinical application for the following reasons:

1. The response, specifically the first wave (p13–n13), is repeatable and consistent. Despite variations in amplitude, the latency is relatively stable.
2. Compared to other tests, VEMP testing may be more specific in locating lesions. It may reveal abnormal function of the saccule and/or the inferior vestibular nerve.
3. Potentially, VEMP testing could be sensitive and able to detect minor changes in the function of the vestibular system.
4. VEMP testing is relatively easy to perform. Most current equipment that is capable of recording the auditory brainstem responses (ABR) can be adapted to record VEMP. Unlike ENG testing, in which 1–2 hours may be needed for a complete evaluation, VEMP testing takes less than an hour. Moreover, the testing does not produce discomfort, and

most people can tolerate the procedure with minimal cooperation. VEMP testing may provide valuable information in diagnosis of the following disorders:

Vestibular neuromma

Since the neural pathway of VEMPs involves the vestibular nerve, VEMP testing could be useful in the evaluation of vestibular nerve function. Murofushi, Matsuzaki, & Mizuno, (1998) reported abnormal VEMPs in 80% of 17 patients with vestibular schwannoma. Fifteen out of the 17 had no VEMPs, while the remaining 2 had significantly decreased amplitude. In another study done by Matsuzaki, Murofushi, and Mizuno (1999), abnormal VEMPs were found in 2 patients with vestibular schwannoma while ABR data were normal. Ochi, Oshashi, & Nishino (2001) also reported 3 vestibular schwannoma cases with abnormal VEMPs, including elevated thresholds, abnormal interaural differences of thresholds, and abnormal p13–n34 amplitude ratios between left and right sides. In contrast, Tsutsumi, Tsunoda, Noguchi, and Komatsuzaki (2000) demonstrated that VEMP results were not always correlated with the nerve where the tumor was located. Moreover, no correlation was found between the VEMPs and tumor size.

Vestibular hypersensitivity disorders

Very loud sounds (over 130 dB SPL) can cause vestibular symptoms in normal participants. Clinically, there are patients who report dizziness or vertigo, imbalance, and discomfort when exposed to everyday noises (Zhou & Cox, 2004). Colebatch et al, (1994) studied VEMPs in a patient with unilateral Tullio phenomenon. They found that the responses elicited from the symptomatic side were large in amplitude and had abnormally low thresholds, but retained normal waveform configuration. They concluded that VEMPs were indicative of a pathological increase in the normal vestibular sensitivity to sound. In a later study, Watson, Halmagyi, and Colebatch (2000) reported similar findings. They studied VEMPs and high-

resolution CT on 4 patients with the Tullio phenomenon. The thresholds of click-evoked VEMPs were low for all affected ears (four at 65 dB, one at 55 dB nHL) and normal (70–90 dB nHL) for the three unaffected ears.

Brantberg, Bergenius, and Tribukait (1999) studied VEMPs on 3 patients with Superior canal dehiscence (SCD). They showed abnormally large responses with low thresholds, particularly in the frequency range of 500–1000 Hz on the affected side. Brantberg et al. (2001) studied 8 patients with SCD. In all patients, VEMPs were present with extremely low thresholds and abnormally large amplitudes on the affected side. In contrast, 4 of the 8 patients had normal hearing, and 6 patients had normal findings with caloric testing. In a recent study by Streubel, Cremer, Carey, Weg, and Minor (2001), 10 patients with SCD were evaluated. For the 8 patients without prior middle ear disease, the VEMP threshold from the affected side was 72 +/- 8 dB nHL, compared to the threshold from normal participants of 96 +/- 4 dB nHL. In the 2 remaining patients with conductive hearing loss, VEMPs were present from the affected side. Given that VEMPs should not be expected in ears with conductive hearing loss, the Streubel, Cremer, Carey, Weg, & Minor, (2001) findings are compelling with regard to the sensitivity of VEMPs in diagnosing SCD in a variety of different hearing conditions.

Vestibular neuritis and differential diagnosis

The use of VEMPs has also been applied to evaluate function of the saccule and inferior vestibular nerve. Halmagyi and Colebatch (1995) studied VEMPs in 22 patients with reported vestibular neuritis. All patients had no caloric responses on the affected sides, indicating dysfunction of the lateral semicircular canal. In contrast, VEMPs were normal in 6 patients, reduced in 5 patients, and absent in 11 patients. Their results not only suggested that VEMPs were not of lateral canal origin but also revealed different pathologies involved in vestibular neuritis.

Acute vestibular neuritis is usually caused by viral infection (Schuknecht & Kitamura, 1981). The inflammation caused by the viral infection can affect superior or inferior vestibular nerves. It is also possible that the viral infection causes inflammation of the entire vestibular ganglion. In the clinic, hallmark signs of acute vestibular neuritis are vertigo, spontaneous nystagmus, and unilateral functional loss of the lateral semicircular canal as shown by caloric testing. Functional loss of the lateral semicircular canal, however, may not be necessary for a diagnosis of acute vestibular neuritis. Halmagyi, Aw, Karlberg, Curthoys, and Todd (2001) recently reported 2 patients with acute vertigo but normal lateral semicircular canal function as indicated by the caloric test. It was reported that these 2 patients had selective inferior vestibular neuritis since VEMPs were absent on the affected side for both cases.

Acoustic neuroma

Murofushi, Matsuzaki, and Mizuno (1999) recorded VEMP in patients with acoustic neuromma. They found that the VEMP responses were present in unaffected side of acoustic neuromas, whereas absent or reduced amplitude responses in the affected side.

Auditory neuropathy

Auditory neuropathy (AN) is characterized by a unique pattern of hearing loss and preservation of outer hair cell function, as revealed by otoacoustic emissions (OAEs) and/or measurable cochlear microphonics on electrocochleography (ECochG). The absence of auditory brainstem responses (ABRs) is thought to be due to a lack of synchronous neural activity (Sheykholeslami, Schmerber, Kermany, & Kaga 2005). The authors measured VEMP in a single patient with bilateral auditory neuropathy and found absent VEMP responses which they attribute to a neuropathy involving the inferior vestibular nerve and/or its end organ, the saccule.

Kumar, Bharti, Sinha, Singh and Barman (2007) recorded VEMP in patients with auditory neuropathy wherein 80% of the ears with auditory neuropathy showed abnormal VEMP results

giving an indication of high incidence of vestibular involvement in the auditory neuropathy population which provides evidence for involvement of the vestibular branch of the VIIIth cranial nerve in a high percentage of the auditory neuropathy population.

Other disorders of the central nervous system

Since the neural pathway of VEMPs includes the central nervous system, it is possible to see abnormal VEMPs in patients with central nervous system disorders. Shimizu, Murofushi, Sakurai, and Halmagyi (2000) reported that latencies of p13–n23 were prolonged in 3 patients with multiple sclerosis. They concluded that latency could be a useful parameter for the evaluation of lesions in the vestibulospinal tract. Murofushi, Shimizu, Takegoshi, and Cheng (2001) also studied the diagnostic value of prolonged latencies in VEMPs. They found that patients with MD or vestibular neuritis showed minimal latency prolongation. In contrast, among 62 patients with vestibular schwannoma, 4 patients were found with prolonged p13 latency, all of whom had large tumors. Moreover, 6 patients with multiple sclerosis showed prolonged p13 latency. The authors suggest that compression of the brainstem or brainstem lesions may contribute to prolongation of VEMP latencies. Versino, Colnaghi, Callieco, Bergamaschi, Romani, and Cosi, (2002) also reported abnormal VEMPs in multiple sclerosis patients.

Absent VEMPs have been reported in patients with brainstem lesions such as Wallenberg's syndrome, which is characterized by sensory deficits affecting the trunk and extremities on the opposite side of the infarct and sensory and motor deficits affecting the face and cranial nerves on the same side with the infarct. Other clinical symptoms and findings are ataxia, facial pain, vertigo, diplopia and dysphagia. The cause of this syndrome is usually the occlusion of the posterior inferior cerebellar artery (PICA) at its origin. (Itoh, Kim, Yoshioka, Kanaya, Enomoto, & Hiraiwa, 2001) and stroke (Chen & Young, 2003). Thus, VEMP testing could be established as a complementary procedure for diagnosis of lesions in the central nervous system.

Meniere's disease (Endolymphatic hydrops)

Meniere's disease (MD) is a fairly common disorder characterized by fluctuating hearing loss, tinnitus, aural fullness, and episodic rotary vertigo. The etiology is still unclear, although histopathology studies have indicated the presence of endolymphatic hydrops. Specific sites of lesion are observed most often in the cochlea, followed by the saccule and utricle. Clinical diagnosis of MD relies mainly on symptoms, electrocochleography (EcochG), and ENG/caloric testing (Zhou & Cox, 2004).

In 1936, Tumarkin first described sudden drop attacks in patients with Meniere's disease (MD). Patients with MD who suffered from drop attacks suddenly felt sensations of being pushed to the ground, and then fell without loss of consciousness. This phenomenon has been called Tumarkin's otolithic crisis or vestibular drop attack (VDA) (Tumarkin, 1936; Black, Effron, & Burns, 1982; Janzen & Russell, 1988; Baloh, Jacobson, & Winder1990). It has been thought that VDA occurs with sudden changes in endolymphatic fluid pressure with inappropriate otolith stimulation causing reflex-like vestibulospinal loss of postural tone. Stimulation of the otolithic organs, the utricle and/or saccule, results in a sensation of linear displacement or tilt. This stimulation may result from mechanical deformation due to pressure differentials within the inner ear or from rapid change in the electrolyte content of the endolymph secondary to the rupture of the membranous labyrinth (Baloh, Jacobson, & Winder, 1990). The abnormal bursts of neural impulses from the otolithic organs would pass through the vestibulospinal tract, resulting in loss of postural tone (Brandt, 1999). These hypothesized pathophysiological mechanisms allowed us to assume that the function of the otolithic organ may be altered at the stage when VDA is observed. In other words, functions of the otolithic end organs may be unstable at that stage.

A recent study of VEMP in patients with VDA secondary to MD reported that the incidence of absent VEMP in the affected ear (n=12) was significantly larger than that in the affected ear in

non-VDA with MD (41% and 13%, respectively) (Timmer et al., 2006). While their findings suggested that VDA could arise from damaged otolithic organs, their results did not reveal reversibility of damage or the possible existence of endolymphatic hydrops in the otolithic organ. Ozeki, Iwasaki, & Murofushi (2008) suggested that the otolithic organs of patients with vestibular drop attack (VDA) secondary to Meniere's disease were damaged but the damage was not complete. In other words, the otolithic functions of patients with VDA were unstable. Their results suggest that the recurrent VDA could occur as a result of the unstable state of endolymphatic hydrops and that the dysfunction of the otolithic organ could be reversible.

Recent works indicates that VEMP testing may bring to the table a new tool for the diagnosis of MD. Robertson and Ireland (1995) reported that VEMPs were absent in all 3 of their patients with MD. De Waele, Huy, Diard, Freyss, and Vidal (1999) also studied VEMPs in patients with MD and reported that 54% of the patients had no VEMPs when clicks were used as stimuli. Shojaku, Takemori, Kobayashi, and Watanabe (2001) reported similar results, in which 8 out of 15 patients with MD had abnormal VEMP amplitudes. Most recently, Ohki, Matsuzaki, Sugasawa, and Murofushi (2002) reported a very interesting finding: absence of or abnormal VEMPs in contralateral ears that may have delayed endolymphatic hydrops. Moreover, 3 hours after administration of glycerol, VEMPs reappeared in two out of four ears. Lin et al., (2006) observed VEMP response in the asymptomatic ear of patients with unilateral MD. The client with unilateral MD showed elevated mean VEMP thresholds and altered VEMP tuning in their symptomatic ears and, to a lesser degree, in their asymptomatic ears. Specific VEMP frequency and tuning criteria were used to define a “Ménière-like”response. This “Ménière-like” response was seen in 27% of asymptomatic ears of their patients with unilateral MD. According to the authors, bilateral involvement is seen in approximately one third of MD cases. Saccular hydrops appears to precede symptoms in bilateral MD. Changes in VEMP threshold and tuning appear to be sensitive to these structural changes in the saccule. If so, then VEMP may be useful as a detector of asymptomatic saccular hydrops and as a predictor of evolving bilateral MD.

MD is a chronic disease and can be classified into four stages based on the degree of hearing loss. Patients in Stage I have pure-tone average (500, 1000, and 2000 Hz) of 0–30 dB HL; Stage II, 31–50 dB HL; Stage III, 51–70 dB HL; Stage IV, >70 dB HL (Black, 1982). Frequently, patients with early MD have normal hearing. If they also have normal ENG/caloric results, diagnosis of MD becomes difficult. Although positive findings in EcochG may indicate hydrops in the cochlea, it does not reveal the saccular condition. Young, Huang, and Cheng, (2003) demonstrated a significant relationship between the interaural amplitude difference ratio of the VEMP response and the stages of Meniere's disease. It is also possible that dynamic changes in VEMPs, such as the frequency tuning feature reported by Todd, Cody, and Banks, (2000), can identify minor physiological and functional changes caused by an altered motion mechanism in early stages of MD.

Rauch, Zhou, Kujawa, Guinan, and Herrmann (2004) reported that the Side-of-disease assignment was most accurate using caloric asymmetry with a 5% interaural difference criterion, achieving 85% correct assignment. The next best method was vestibular evoked myogenic potentials using 250-Hz tone burst stimuli, achieving 80% correct assignment. The least accurate method was caloric asymmetry using a traditional 30% interaural difference limen, achieving 55% correct assignment. Vestibular evoked myogenic potentials threshold was shown to be highly sensitive to side-of-disease in unilateral Meniere's disease and also vestibular evoked myogenic potentials supplies information complementary to that provided by other components of the vestibular test battery.

Rauch et al, (2004) studied the changes in the dynamics of VEMP due to the alteration in saccular motion seen in cochleosaccular hydrops. In their study, normal subjects showed a frequency-dependent vestibular evoked myogenic potential threshold, with best response ("frequency tuning") at 500 Hz. Whereas, affected Meniere's ears had significantly increased

vestibular evoked myogenic potential thresholds. Affected Meniere's ears showed threshold shifts at all frequencies and there was less tuning apparent at 500 Hz. Unaffected ears of Meniere's subjects also showed significantly elevated vestibular evoked myogenic potential thresholds compared with normal subjects. Analyses of vestibular evoked myogenic potential thresholds for effects of age, hearing loss, and audiometric configuration showed no significant differences. They concluded that Meniere's ears display alterations in vestibular evoked myogenic potential threshold and tuning, supporting the hypothesis of altered saccular motion mechanics arising from hydropic distention. Unaffected ears of unilateral Meniere's subjects showed similar changes, though to a lesser degree. This finding may be because of occult saccular hydrops in the asymptomatic ear or binaural interactions in the vestibular evoked myogenic potential otolith-cervical reflex arc.

Osei-Lah, Ceranic, and Luxon (2008) distinguished acute and stable Meniere's disease using VEMP responses. According to them, the parameter that best differentiated acute from stable Meniere's disease at threshold was the interaural amplitude difference ratio. Therefore, this parameter may be used to monitor the clinical course of Meniere's disease.

Sheykholeslami, Megerian, and Zheng (2009) for the first time studied the VEMP recordings in mice and reported abnormal VEMPs in a mouse model with endolymphatic hydrops (EDH). The characteristics of these potentials such as higher response threshold in comparison to auditory brainstem response, myogenic nature of the response, and latency correlation with the cervical recording (accessory nerve nucleus) were similar to those of VEMPs in humans, guinea pigs, cats, and rats, suggesting that the mouse may be used as an animal model in the study of VEMPs.

Benign Paroxysmal Positional Vertigo

Benign paroxysmal positional vertigo (BPPV) seems to occur because of otoconia migration into the semicircular canals or their adherence to the cupula. Although the origin of these otoconia lies in the macula of the utricle, vestibular evoked myogenic potentials (VEMPs) can be used assess saccular function (Zhou & Cox, 2004).

Heide et al, (1999) studied the usefulness of VEMP in the differential diagnosis of acute vertigo of presumed vestibular origin and they compared VEMP responses with standard Caloric reaction (CR) test. In comparison with CR, VEMP showed a sensitivity of 59% and a specificity of 100% for peripheral vestibular disorders.

Akkuzu, Akkuzu, and Ozluoglu (2006) investigated the efficacy of VEMP in individuals with Meniere's disease and BPPV. They found that the rate of VEMP abnormalities in the control ears was significantly lower than the corresponding rates in the affected BPPV ears and the affected Meniere's ears that were studied ($P=0.012$ and $P<0.001$, respectively). Their results suggested that testing of VEMP is a promising method for diagnosing and following patients with BPPV paroxysmal positional vertigo and Meniere's disease.

Boleas-Aguirre, Sánchez-Ferrándiz, Artieda, and Pérez (2007) found a lack of VEMP response in 52 % of the ears with BPPV. When adjusted for bilateral absence, VEMP response was absent in 20.3 % of ears, thereby concluding that some patients with idiopathic BPPV show a degree of saccular dysfunction.

Yang, Kim, Lee, and Lee (2008) measured vestibular evoked myogenic potential in BPPV patients which showed prolonged p13 and n23 latencies compared with those of the normal group. They could not find any significant difference in VEMP latencies between patients with posterior and horizontal canal type of BPPV. VEMP latencies are increased in BPPV patients, which may signify neuronal degenerative changes in the macula of the

saccule. When an extensive neuronal damage was suspected by VEMP results such as "no response" in VEMP, the disease progress showed a chronic and resistive course.

Hong, Kim, Yeo, and Cha (2008) investigated vestibular evoked myogenic potentials (VEMPs) as a function of age and the involvement of each of the 3 semicircular canals in patients with benign paroxysmal positional vertigo (BPPV). They found that the patients with BPPV may show abnormal VEMP findings, irrespective of the involved semicircular canal, and age effect was associated with VEMP results suggesting degeneration of the maculae of the saccule.

Hong et al. (2008) interpreted VEMP findings in patients with the three major peripheral vertigo diseases, taking age-related changes into consideration and found different abnormal VEMP rates among the three diseases, as well as differences in the proportion of parameters that were abnormal, according to the type of disease. Abnormal VEMP rates in the vestibular neuritis, BPPV, and Meniere's disease groups were 36.6%, 25.8%, and 69%, respectively. The proportion of prolonged p13 latency in BPPV patients with abnormal VEMP responses was relatively high compared with the other two diseases. VEMP asymmetry in the patients with Meniere's disease was relatively high.

Heide et al. (1999) investigated VEMPs in the differential diagnosis of acute vertigo. These authors evaluated 40 patients with acute vertigo: 26 with acute peripheral vestibulopathy, 5 with MD, 3 with BPPV, and 6 with psychogenic vertigo. These authors found 12 of 29 patients had normal VEMPs with abnormal caloric tests. Further review of their study yielded the following findings:

1. All patients with BPPV had normal VEMPs.

2. All patients with psychogenic vertigo had normal VEMPs.

3. In the 17 patients who had abnormal VEMPs, 5 had no VEMPs in either ear, while caloric testing revealed only unilateral loss.

4. More than 5 weeks after the onset of vertigo, VEMPs had reappeared in 2 patients with acute vestibulopathy, while in the patient who lost vestibular function due to trauma, VEMPs had not returned more than 9 months after the accident. This study suggested that VEMP testing was useful in the diagnosis of acute vertigo regarding the location and nature of the disorder.

In a similar study, Murofushi et al, (1996) found that in a population of patients with vestibular neuritis, presence or absence of VEMPs would predict subsequent BPPV occurrence. In 47 patients with acute vestibular neuritis, 10 had subsequent BPPV posterior canal on the same side as the neuritis. All 10 patients with BPPV had VEMPs in spite of the vestibular neuritis, whereas 16 patients revealed absent VEMPS. The authors concluded that if VEMPs are absent at the time of the acute neuritis, the patient is unlikely to develop consequential BPPV.

In conclusion, Vestibular evoked myogenic potential (VEMP) is an electromyographic response to loud auditory stimuli that is recorded in the sternocleidomastoid muscle during tonic contraction. VEMP is a valuable clinical tool in the differential diagnosis of various conditions affecting the normal physiology of the vestibular system by providing information on otolith function and the functional integrity of the inferior vestibular nerve. Since there is a capital need to differentiate the most common conditions such as Meniere ’s disease and benign paroxysmal positional vertigo, which presents with almost similar patterns of symptoms thereby, affecting the proper differential diagnosis of these cases. Hence, in this present study, VEMP has been taken as a reliable tool to check for the differences in the responses recorded from these clients.

3. METHOD

The main aim of the study was to identify the pattern of VEMP's recorded from individuals with conditions indicating disturbances of vestibular system and to compare it with the VEMP's recorded from normal individuals. Three groups of subjects were taken to arrive at the objectives.

Subjects

A total of 75 ears of 43 subjects were taken for the study. They were divided into three groups. Group I consisted of individuals with normal hearing sensitivity without vestibular symptoms served as the control; group II consisted of individuals who were diagnosed as having Meniere's Disease, and group III consisted of individuals who were diagnosed as having BPPV by an otologist.

Group I: Consisted of 33 ears of 20 individuals with normal auditory and vestibular functioning as ruled out by detailed case history served as the control group. These

individuals were between the age range of 18-24 years with a mean age of 20.45 years. The subjects were selected based on the following criteria:

Selection Criteria

- Audiometric pure tone thresholds were within 15 dB HL in octave frequencies from 250 Hz to 8000 Hz for air conduction and between 250 Hz and 4000 Hz for bone conduction.
- Uncomfortable level was equal to or greater than 100 dB HL for Speech.
- All the subjects had 'A' type tympanogram with acoustic reflex threshold within normal limits, indicating a normal middle ear function.
- Auditory brainstem evoked response (ABR) results did not indicate of having space occupying lesions (retro cochlear pathology).
- No relevant otologic history was present in those subjects.
- No history of any observable medical or neurological signs.

Group II: Consisted of 22 ears of 12 individuals with suspected Meniere's disease. Out of 12 individuals 8 individuals had bilateral and 4 individuals had unilateral indications of Meniere's disease. These individuals were between the age range of 20-60 years with a mean age of 41.3 years.

Selection Criteria

- The hearing sensitivity varied from normal hearing sensitivity to severe sensori-neural hearing loss.
- All the subjects had uncomfortable level greater than 100 dB HL for Speech.
- All of them had 'A' type tympanogram with normal, elevated or absent acoustic reflexes.
- No relevant history of middle ear pathology was reported.
- All of them were devoid of having retro cochlear pathology (RCP), which was ruled out based on ABR results.

- The subjects were diagnosed as having Meniere's disease by an experienced otologist or a neurologist.
- All the subjects had the triad symptoms of Meniere's disease: fluctuating hearing loss, tinnitus and, giddiness.

Group III: This group had 21 ears from 11 individuals with suspected BPPV. The mean age of this group was 39.7 years with a range of 20 to 60 years.

Selection Criteria

- All the subjects had either normal hearing sensitivity or mild sensori-neural hearing loss.
- Uncomfortable level was greater than 100 dB HL for Speech.
- All the subjects had 'A' type tympanogram with normal, elevated or absent acoustic reflexes.
- No relevant history of middle ear pathology was reported.
- ABR results did not indicate presence of RCP.
- The subjects were diagnosed as having BPPV by an experienced otologist or a neurologist.
- All of them had the symptoms of BPPV (tinnitus, and giddiness induced by rapid head movement).

Instrumentation:

- A Calibrated diagnostic audiometer, Grason Stadler Inc-61 (GSI-61) used to obtain pure tone thresholds and uncomfortable level.
- A Calibrated GSI Tympstar immittance meter was used for tympanometry and reflexometry.

- Intelligent hearing system (IHS version 4) was used to tap both auditory brainstem responses and vestibular evoked myogenic potentials.

Test Environment

The testing was carried out in a sound treated room. The ambient noise level was within the permissible limits (ANSI 1991; S3.1).

Procedure

The control group was selected for further evaluations by administering a detailed case history wherein the subjects reported to have normal hearing sensitivity without any history of middle ear pathology and also normal vestibular functioning without any history of vertigo, giddiness and nausea. Similar history was taken for subjects showing positive signs of vestibular disorders such as giddiness, vertigo and nausea and also subjects with fluctuating hearing loss along with the balancing problem. The subjects selected through the case history were assessed using the following examinations.

1) *Pure tone audiometry*: wherein the behavioral thresholds in octave frequencies from 250 Hz to 8000 Hz for air conduction and 250 Hz to 4000 Hz for bone conduction were obtained. The thresholds were tracked using the modified Hughson and Westlake method (Carhart & Jerger, 1959).
2) *Uncomfortable level*: were measured using speech stimuli to rule out presence of recruitment and tolerance problem since the stimuli used to record the evoked potentials were of higher intensity.
3) *Tympanometry* and *Reflexometry*: were done using 226 Hz probe tone. Acoustic reflex thresholds were established at 500 Hz, 1 kHz, 2 kHz and 4 kHz pure tones.

4) *Auditory brainstem responses*: were done to rule out retro cochlear pathology involving auditory nerve. The stimulus and acquisition parameters used to record ABR are shown in the Table 3.1.

Table 3.1 Protocol used to record ABR.

Stimulus Parameters		**Acquisition parameters**	
Stimulus	Click	*Mode*	Monaural stimulation
Duration	100 micro sec	*Electrode type*	Disc electrode
Stimulus rate	11.1/sec and 90.1/ s	*Electrode montage*	Ground: non test ear mastoid (M_i) Non inverting : forehead (Fpz) Inverting : test ear mastoid (M_i)
Polarity	Rarefaction	*Analysis window*	15 ms
No. of Sweeps	1500	*Filter settings*	100 Hz – 3000 Hz
Intensity	90 dB nHL	*Notch Filter*	On
Transducer	ER-3A insert receive	*Impedance*	Inter electrode : 2 K ohm Intra electrode : 5 K ohm
		No of channels	Single channel
		Replicability	Twice
		Gain	1,00,000
		Artifact rejection	40 micro volts

Inter wave latency were recorded using 11.1/ sec repetition rate and wave morphology and presence or absence of ABR wave was noted using 90.1/ sec to identify

retro-cochlear pathology (RCP). Those who had normal inter wave latency and good morphology at 90.1/ sec was considered as not having RCP and was included for the study.

All the subjects selected for the study have undergone VEMP recording. Procedure cited below has been adopted to record VEMP. The subjects were placed in a comfortable environment, where the subjects were made to sit upright position on an arm chair. The subjects were asked to turn their head to one side (opposite to the ear being stimulated) to tense the Sternocleidomastoid (SCM) muscle. The SCM muscle tension were monitored to be within 30–100 micro volt Electromyographic (EMG) level for the reliable recording of VEMP responses.

An evoked potential system (Intelligent Hearing Systems, version 4.0) was used to generate the acoustic stimulus as well as to measure acoustically evoked VEMP responses. Parameters used to record VEMP (Damen, 2007) are shown in the Table 3.2.

Table 3.2 Protocol used to record VEMP.

Stimulus Parameters		Acquisition Parameters	
Stimulus	500 Hz Tone Burst	*Mode*	Ipsilateral
Duration	10 ms	*Electrode type*	Disc electrode
Stimulus rate	5.1 per sec	*Electrode montage*	Ground: Forehead Non inverting : middle portion of Sternocleidomastoid (SCM) Inverting: : Sterno-clavicular junction
Polarity	Alternating	*Analysis window*	-30 to 70 ms
No. of Sweeps	200	*Filter settings*	10 to 1500 Hz
Intensity	95 dBnHL	*Notch Filter*	Off
Transducer	ER 3A Insert receiver	*Impedance*	Intra electrode : < 5 k ohm Inter electrode: within 2 k ohm

Electrode placement:

Each electrode sites were first cleaned by scrubbing with cotton soaked in skin preparing paste. The electrodes were then dipped in to skin conduction paste and fixed on the scalp sites using surgical tape.

Acoustically evoked VEMPs were recorded twice to check for its reliability and stored in the computer. Later it was retrieved and shown to three audiologists independently to identify the VEMP waves. The p13 and n23 peak latency and also peak to peak amplitude was noted, if there was an agreement in identifying peaks among the

audiologists. The interaural amplitude difference ratio was calculated for all the three groups.

Analysis

The latency and amplitude noted were subjected to statistical analysis.

- The mean latency of p13 and n23 peaks was compared across the groups to find out any significant difference between the groups.
- Similarly, peak to peak amplitude was compared and evaluated across the groups.
- The mean VEMP latency and amplitude of right ear were compared with left ear responses across the groups.
- The interaural amplitude difference ratio was also compared across the groups for presence of significant difference.
- For Unilateral Meniere's disease group, ear effect was found by comparing the mean latency values and peak to peak amplitude between right and left ear respectively.

4. RESULTS

The aim of the present study was to identify the pattern of VEMP responses using 500 Hz tone burst in individuals with Meniere's disease, benign paroxysmal positional vertigo and also individuals with normal auditory and vestibular functioning. The study was also aimed to differentiate the groups by comparing the latencies of p13, n23 and its peak-to-peak amplitude of VEMP responses across the three mentioned groups. Also an ear-wise comparison was made for each of the groups for its latencies and amplitude measures. The interaural amplitude ratio difference (IADR) was calculated and compared across the groups to observe for any significant difference. The ear wise comparison was made for individuals with unilateral Meniere's disease. The latencies, amplitude and IADR were analyzed using statistical package for social sciences (SPSS) software, version 16.

The present study had two variables which were mentioned below:

- Independent variables: Age, gender, ear and group.
- Dependent variables: Latency and Amplitude

The following statistical analyses were carried out within and across each group of subjects:

- Descriptive statistics was done to obtain the mean and standard deviation for all the parameters of VEMP.
- Multivariate Analysis of Variance (MANOVA) was done to check for significant differences in the VEMP parameters across the groups.
- Duncan's Post Hoc test was administered to analyze which parameter shows significant difference between the groups.

- Kruskal wallis test to cross check duncan's test, since the sample size were uneven across the groups.
- Mann Whitney U test was done to compare the Inter aural amplitude difference ratio (IADR) across the groups.
- Paired t-test was done to check for ear differences in VEMP parameters for individuals with normal hearing sensitivity and no vestibular symptoms.
- Wilcoxon's signed ranks test was done to see for the ear differences in the parameters of VEMP for individuals with Meniere's disease (Group II) and individuals with benign paroxysmal positional vertigo (Group III) respectively.

VEMP responses in Group I:

The VEMP response in an individual with normal auditory and vestibular functioning is characterized by a biphasic waveform with a positive peak arising at around 13 ms called as p13 and a negative peak called n23 which arises at about 23 ms approximately. The VEMP response obtained from an individual with normal auditory and vestibular functioning is shown in the Figure 4.1.

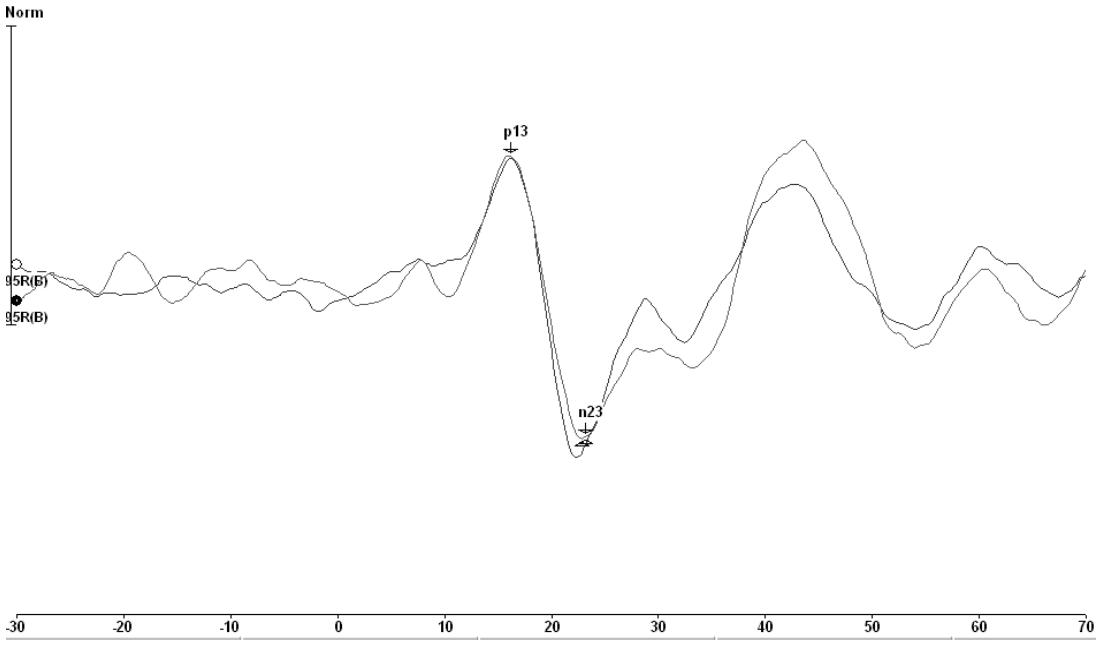

Figure 4.1: VEMP response showing p13 and n23 peaks recorded for a 500 Hz tone burst presented at 95 dB nHL in an individual with normal auditory and vestibular functioning.

The percentage of occurrence of VEMP in Group I was about 100% with good wave morphology at the given intensity level of 95 dB nHL. This indicates normal functioning and coordination of auditory and vestibular system and its pathways in the subjects of group I.

VEMP responses in Group II:

The VEMP was present in 9 out of 21 ears (42%) with Meniere's disease (MD) tested. The PAMR was recorded from individuals with MD whose degree of hearing loss varied from mild to moderately severe sensorineural hearing loss. Eight out of nine ears, which showed VEMP responses was noisy and had poor wave morphology. Only 1 ear's response was less noisy and with a good wave morphology. The following figure shows the VEMP response recorded from an individual with MD.

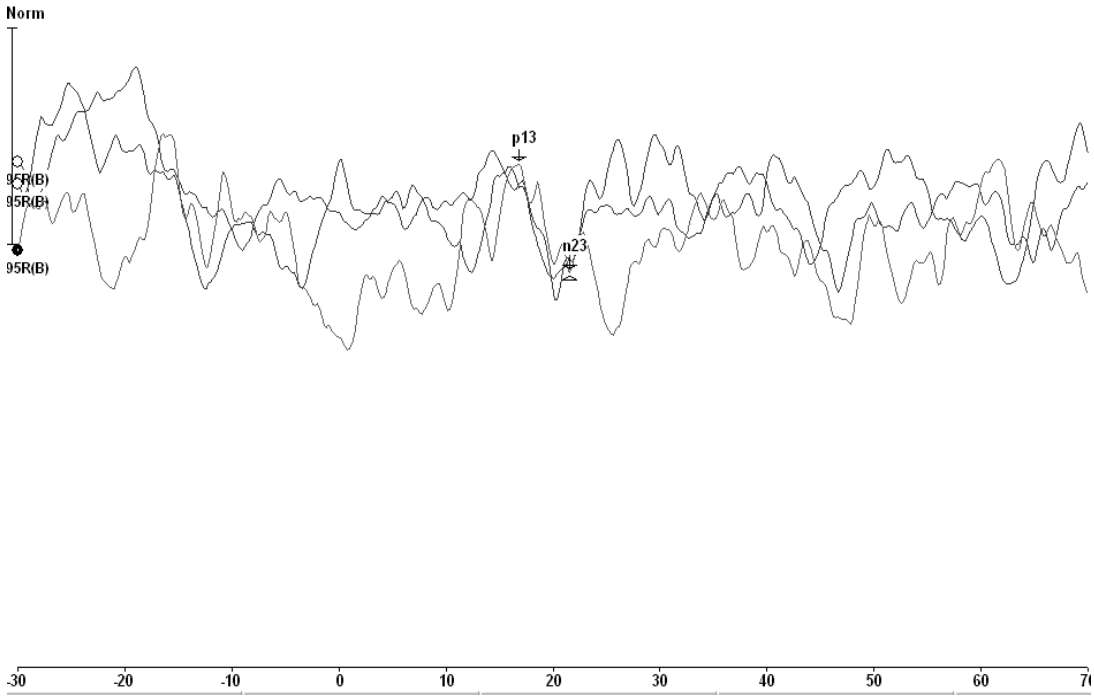

Figure 4.2: *VEMP response showing p13 and n23 peaks recorded for a 500 Hz tone burst presented at 95 dB nHL in an individual with MD.*

VEMP responses in Group III:

The VEMP responses were present in 12 out of 20 ears (60%) recorded in individuals with Benign paroxysmal positional vertigo (BPPV) whose hearing threshold varied from normal to mild sensorineural hearing loss. Six out of 12 ears which showed recordable VEMP responses had poor wave morphology and it was too noisy. The rest 6 ears showed comparatively better responses and morphology. The following figure shows the noisy VEMP response (a) and good morphology (b) obtained in individuals with BPPV.

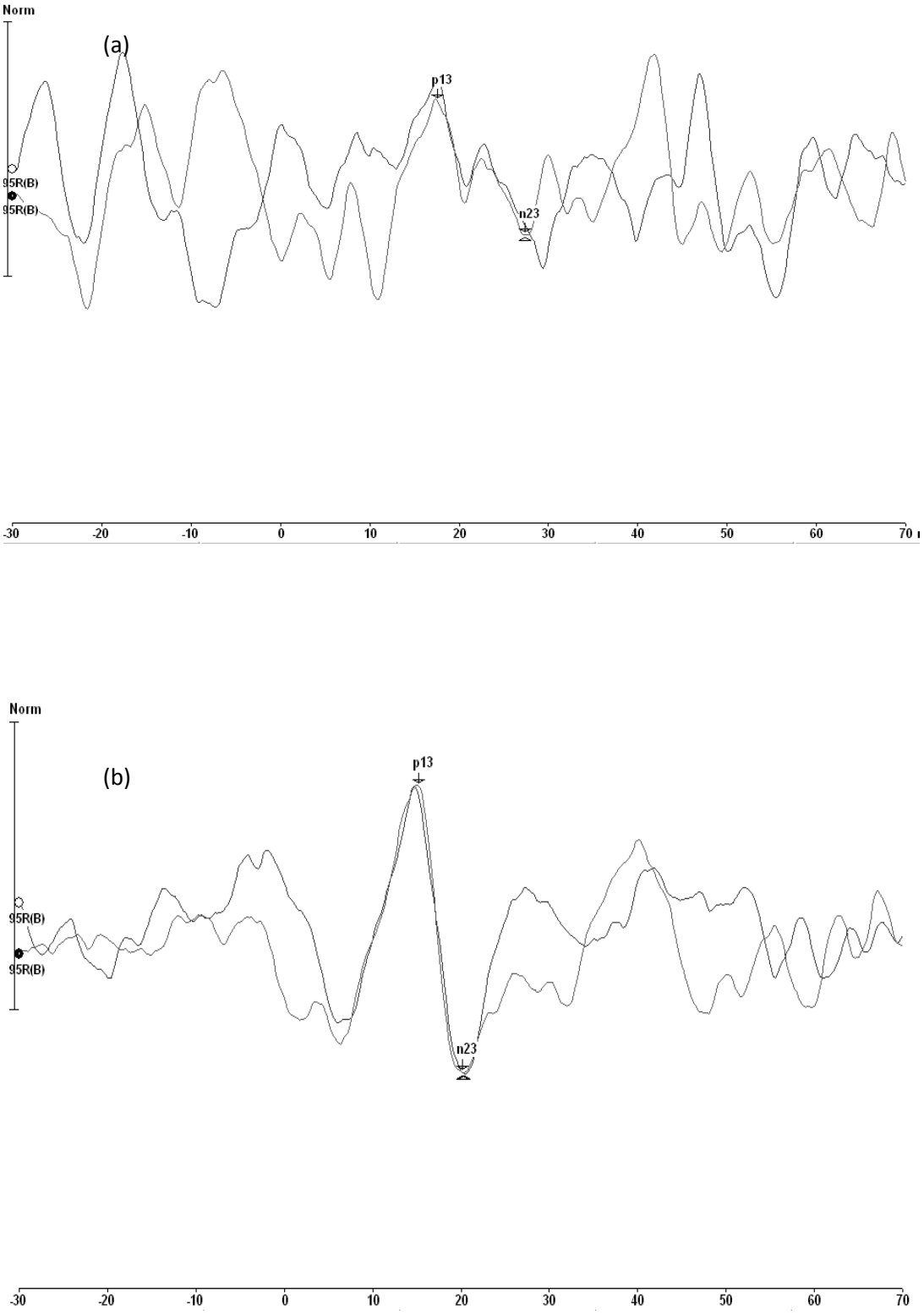

Figure 4.3: *VEMP response showing p13 and n23 peaks recorded for a 500 Hz tone burst presented at 95 dB nHL in individuals with BPPV.*

Between the ear comparison

The p13, n23 latency and peak to peak amplitude (PPA) obtained from all the three groups were compared between right and left ear. The mean latency, peak to peak amplitude and the SD were calculated.

Between the ear comparison for normal group:

The mean latency values of p13 and n23 were calculated. The details are shown in the table 4.1. It can be seen from the table that mean latency values obtained between the ears did not show much difference. Also, the mean peak to peak amplitude values obtained between the ears were not much different. To see the significant difference in p13 and n23 latency and peak to peak amplitude between the ears paired t-test was done. The results did not show any significant difference between the ears for any of the VEMP parameters.

Table 4.1:

Mean and SD of p13, n23 latency and peak to peak amplitude and also the t-values with significance level between the ears in individuals with normal auditory and vestibular functioning.

Parameters	Right ear	Left ear	*t-value*	*Level of significance*
P13	13.5750	14.0625	0.916	*0.374*
N23	21.1250	20.8938	0.496	*0.627*
PPA	55.8119	62.5863	0.593	*0.562*

Between the ear comparison for MD group:

The mean latency values of p13 and n23 were calculated. The details are shown in the table 4.2. It can be seen from the table that mean latency values obtained between the ears did not differ much. The mean peak to peak amplitude values obtained between the ears showed some variation. To see the significant difference in p13 and n23 latency and peak to peak amplitude between the ears Wilcoxon's signed rank test was done. The results did not show any significant difference between the ears for any of the VEMP parameters.

Table 4.2:

Mean and SD of p13, n23 latency and peak to peak amplitude and also the Z-values with significance level between the ears in individuals with MD.

Parameters	Right ear	Left ear	Z-value	*Level of significance*
P13	16.4250	16.7500	1.069	*0.285*
N23	22.5250	22.2500	1.069	*0.285*
PPA	27.6788	20.9475	0.535	*0.593*

Ear wise comparison for BPPV group:

The mean latency values and SD of p13 and n23 were calculated. The details are shown in the table 4.3. It can be seen from the table that mean latency values obtained between the ears varied slightly. The mean peak to peak amplitude values obtained between the ears also had slight difference. To see the significant difference in p13 and n23 latency and peak to peak amplitude between the ears Wilcoxon's signed rank test was done. The results did not show any significant difference between the ears for any of the VEMP parameters.

Table 4.3:

Mean and SD of p13, n23 latency and peak to peak amplitude and also the Z-values with significance level between the ears in individuals with MD.

Parameters	Right ear	Left ear	Z-value	*Level of significance*
P13 (ms)	19.1600	16.8571	0.271	*0.786*
N23 (ms)	26.4000	24.7143	0.272	*0.785*
PPA (micro volts)	27.1220	31.3957	0.135	*0.893*

Comparison of VEMP responses between the groups

A group comparison was made by comparing the responses recorded from the three groups by analyzing the latencies of p13 and n23 peaks and the peak to peak amplitude. Also the mean and standard deviation for the individual parameters were calculated using descriptive statistics. For the group comparison the VEMP responses of right and left ear were combined for all the groups as there was no significant difference in latency or amplitude values between the ears for all the groups. The results obtained are given in the Table 4.4.

Table 4.4:

Mean, Range and SD for VEMP parameters obtained in all the groups.

Group		p13	n23	PPA
Normals	*Mean*	13.81	21.00	59.19
	SD	1.66	1.97	24.50
	Range	9.40 - 18.00	17.00 - 24.40	1.54 - 104.60
MD	*Mean*	16.53	22.43	25.44
	SD	2.54	3.64	15.11
	Range	11.40 - 19.60	16.20 - 29.40	6.29 - 47.00
BPPV	*Mean*	17.81	27.08	29.61
	SD	5.48	6.21	15.67
	Range	9.60 - 27.00	18.20 - 36.00	3.26 - 59.87

It is apparent from the table that the latency values obtained from individuals with normal auditory and vestibular functioning were shorter when compared to the clinical group. Within the clinical group, MD group's latency was shorter than the BPPV group. Also, BPPV group had largest variation for the latency values than the MD group and individuals with normal auditory and vestibular functioning. For the p13 and n23 peak latency, responses recorded from BPPV group

were prolonged the most, whereas the normal auditory and vestibular functioning group had the earliest latencies. Individuals with normal auditory and vestibular functioning were recorded with the highest peak to peak amplitude followed by BPPV group and the MD group which had the least peak to peak amplitude. Also, there was maximum variation in the peak to peak amplitude recorded from individuals with normal auditory and vestibular functioning, whereas the MD group had the least variation.

To see the significant difference among the latencies of p13 and n23 and peak to peak amplitude of the VEMP responses recorded from the three groups, MANOVA was done. The results of the MANOVA revealed that there was a significant difference in the latencies of p13 [$F(2, 53) = 8.912$, $p<0.001$], n23 [$F(2, 53) = 12.335$, $p<0.001$] and also for the peak to peak amplitude [$F(2, 53) = 15.414$, $p<0.001$] across the three groups.

Since, there was uneven sample size among the three groups taken for the study due to presence of no responses which cannot be taken for statistical analysis; Kruskal-wallis test was done to cross check the results of the MANOVA. The results of Kruskal-wallis also revealed that there was a significant difference in the latency values of p13, n23 and peak to peak amplitude respectively which is in accordance with the results of MANOVA (Table 4.5).

Table 4.5:

Chi square values along with significant level across the groups obtained for VEMP parameters.

Parameter	**Chi Square Value**	**Degree of Freedom**	**Sig. Level**
p13	12.996	2	***.002****
n23	9.171	2	***.010****
PPA	21.273	2	***.000****

Duncan's Post hoc test was done to compare the latencies of p13 and n23 and peak to peak amplitude between any two groups since the MANOVA showed significant differences across the groups. The results of Duncan's test are given in the following tables.

Table 4.6:

Duncan's Post hoc test results for p13 latency between the groups.

Groups	Subset	
	1	2
Normals	13.8188	
MD		16.5333
BPPV		17.8167

For the positive peak p13, it can be observed from the table 4.6 that the individuals with normal auditory and vestibular functioning group had significantly shorter p13 latency than the individuals with MD and BPPV group. However, individuals with MD and BPPV group did not differ significantly in the p13 latency obtained.

Table 4.7:

Duncan's Post hoc test results for n23 latency between the groups.

Groups	Subset	
	1	2
Normals	21.0094	
MD	22.4333	
BPPV		27.0833

There was no significant difference in n23 latency observed between normal group and MD group. However, BPPV group significantly differed from the other two groups.

Table 4.8:

Duncan's Post hoc test results for peak to peak amplitude between the groups.

Groups	Subset	
	1	2
MD	25.4433	
BPPV	29.6150	

Normals		59.1991

For the peak to peak amplitude, there was no significant difference in peak to peak amplitude observed between MD group and BPPV group. Whereas, there was a significant difference observed when compared with individuals with normal auditory and vestibular functioning group.

Inter aural amplitude difference ratio (IADR)

The mean IADR was calculated for normal group and MD group only and not for BPPV group since only two patients showed bilateral VEMP responses which cannot be considered for statistical analysis. The mean and SD of IADR value was calculated for the normal and MD group which is given in the figure 4.4.

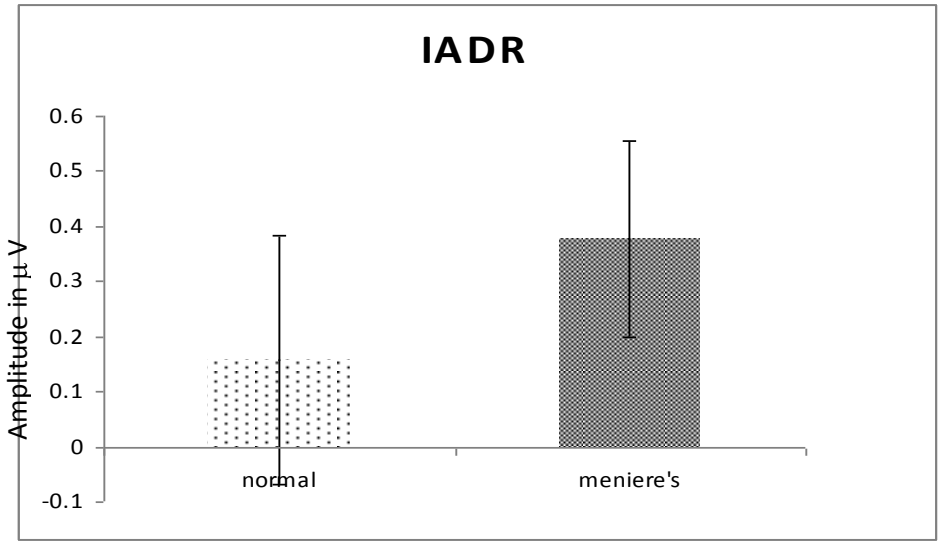

Figure 4.4: Mean and SD values of IADR measured for normal group and MD group.

The mean IADR of MD group (0.3775) is greater than the IADR of normal group (0.1578). The Mann Whitney-U test was done to see the significant difference in IADR values between the groups. The results revealed a significant difference between the IADR values of normal group and MD group ($Z = 2.551$, $p < 0.05$).

Ear effect in Meniere's disease (MD) group

Out of 12 individuals with MD, 4 of them had unilateral MD. The mean latencies of p13 and n23 from the unaffected side of the unilateral subjects were 16.95 ms and 24.05 ms respectively. And the mean peak to peak amplitude in these subjects was 25.48 micro volts. However, in the affected side 2 individuals showed absent VEMP responses and the others showed prolonged latencies and reduced amplitude values.

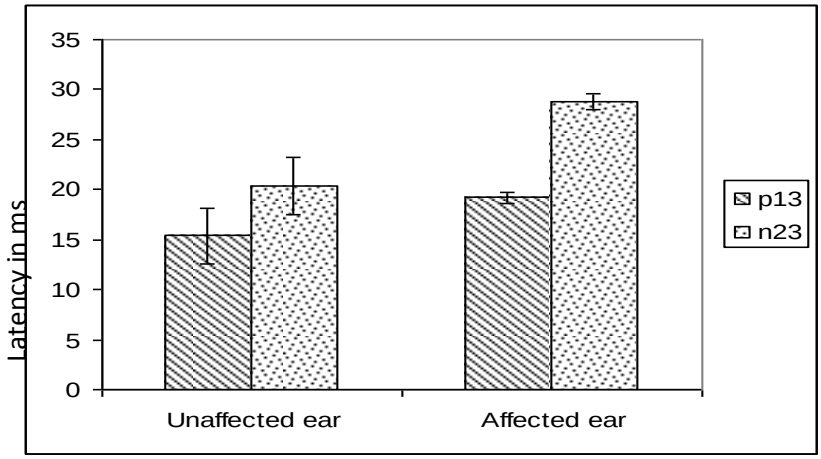

Figure 4.5: Mean and SD latency of p13 and n23 for the unaffected and affected ear obtained in the unilateral Meniere's disease individuals.

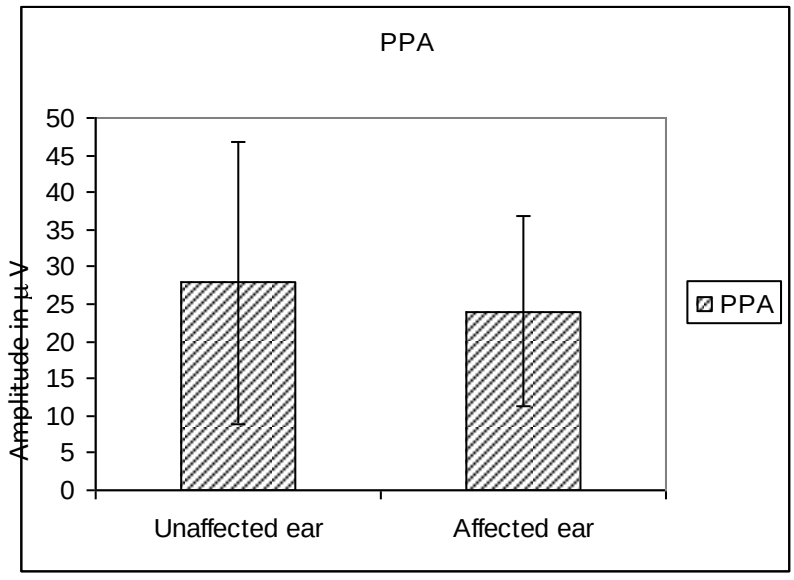

Figure 4.6: Mean and SD of peak to peak amplitude values for the unaffected and affected ear obtained in the unilateral Meniere's disease individuals.

Table 4.9:

Z-values and significant levels of the VEMP parameters for individuals with unilateral Meniere's disease.

Unaffected ear Vs Affected ear	Z-value	*Level of Significance*
P13	1.342	*.180*
N23	1.342	*.180*
PPA	0.447	*.655*

The Wilcoxon's signed rank test done to compare the latency and amplitude between the unaffected and affected ears of unilateral MD group. The result showed that there were no significant differences among latency and amplitude values between the ears. Whereas, descriptively the latency of p13 and n23 of the unaffected ears were shorter than the latency values of the affected ears. The amplitude of unaffected ears showed greater value than the affected ears. Hence, the VEMP responses were either absent or delayed in latency and reduced in amplitude in the affected ear when compared with the responses from the unaffected ear.

It can be concluded from the results that the

1. VEMP results failed to show any significant latency and amplitude difference between the ears.
2. VEMP latency was shortest for the control group and longest for the BPPV group.

3. Peak to peak amplitude was more for control group and was least for individuals with MD.
4. IADR values were more for the MD group.
5. Within the clinical group individuals with BPPV showed prolonged latency and increased amplitude than individuals with MD.
6. Individuals with unilateral MD showed abnormal VEMP result in the affected ear and normal result in unaffected ear.

5. Discussion

The aim of the present study was to identify the pattern of VEMP responses in individuals with MD and also individuals with BPPV and to compare the results with VEMP responses recorded from individuals with normal auditory and vestibular functioning. The VEMP responses were also compared across the groups to check for any significant difference in the parameters recorded. The IADR was also calculated for all the groups and compared. The present study also assessed the ear wise difference among the VEMP responses obtained from the three groups. Finally, response asymmetry was assessed in individuals with unilateral MD.

5.1 VEMP responses in individuals with normal auditory and vestibular functioning

The present study revealed a 100% response rate in individuals with normal auditory and vestibular functioning. This is in accordance with the study by Castelein, Deggouj, Wuyts and Gersdorff, (2008). According to their study VEMP responses were present in all individuals below the age of 60 years.

The mean p13 and n23 latencies recorded in the present study were 13.81±1.66 ms and 21±1.97 ms respectively. Welgampola and Colebatch (2001) found that the average p13 and n23 latencies to a tone burst stimulus were 13.1 and 22.8 ms respectively. Wang and Young (2001) obtained VEMP responses in individuals with normal auditory and vestibular functioning and the mean p13 and n23 latencies were 13.5 ± (0.8) ms and 21.2 ± (1.8) ms respectively.

The peak to peak amplitude obtained in the present study was 59.19±24.50 micro volts with a wide range from 1.54 to 104.60 micro volts. Castelein, Deggouj, Wuyts, & Gersdorff. (2008) also cited that the amplitude of the p13 n23 varies widely among individuals making it difficult to use the amplitude parameter for clinical evaluation.

5.2 VEMP responses in individuals with Meniere's disease

The present study recorded VEMP responses from 42% of individuals with MD with poor wave morphology. De Waele et al, (1999) reported a 46% response rate recorded from individuals with MD. Hong et al, (2008) recorded a response rate of about 31% in individuals with MD. However, it has also been demonstrated that VEMP responses can be augmented in cases of saccular hydrops, (Young, Wu & Wu, 2002).

The mean p13 and n23 latency in the present study was 16.53±2.54 ms and 22.43±3.64 ms respectively. The mean peak to peak amplitude was about 25.44±15.11 micro volts. Hong et al (2008) obtained the mean p13 and n23 latency of about 17.1±3.2 ms and 23.0±3.2 ms respectively and also the peak to peak amplitude of about 20.8±19.7 micro volts.

In the current study 58% of individuals with MD showed absent VEMP responses. Robertson and Ireland (1995) reported that VEMPs were absent in all 3 of their patients with MD. De Waele et al, (1999) also studied VEMPs in patients with MD and reported that 54% of the patients had no VEMPs when clicks were used as stimuli. Shojaku, Takemori, Kobayashi, and Watanabe (2001) reported similar results, in which 8 out of 15 patients with MD had abnormal VEMP amplitudes. Most recently, Ohki, Matsuzaki, Sugasawa, and Murofushi (2002) reported a very interesting finding: absence of or abnormal VEMPs in contralateral ears that may have delayed endolymphatic hydrops. Moreover, 3 hours after administration of glycerol, VEMPs reappeared in two out of four ears. The prolongation of the peak latency can be attributed to the effect of hydrops on the cochlear mechanism which hinders the efficient sound transmission to the saccular maculae.

5.3 VEMP responses in individuals with BPPV

The present study recorded VEMP responses from individuals with BPPV with a response rate of 60% and the mean p13 and n23 latencies were 17.81±5.48 ms and 27.08±6.21 ms

respectively whereas the mean peak to peak amplitude was 29.61±15.67 micro volts. Hong et al, (2008) recorded VEMP responses in 75% of individuals with BPPV with mean p13 and n23 latency of about 16.5±2.6 ms and 22.6±2.8 ms respectively with mean peak to peak amplitude of about 15.3±22.0 micro volts. Akkuzu, Akkuzu and Ozluoglu, (2006) found prolonged p13 and n23 latencies when compared to normal individuals with a response rate of 70%.

5.4 Ear wise comparison for normal group

The latency of p13 and n23 and the peak to peak amplitude compared between right and left ear were not statistically significant in the present study. Young and Kuo, (2004) investigated side difference by using binaural sequential stimulation with an alternating intensity and found mixed ear dominance only in the p13 and n23 latencies whereas there was no ear difference reported for the peak to peak amplitude. In the present study, the absence of ear difference may be due to the type of stimulation used, which is an ipsilateral stimulation and also a single constant intensity stimulus was used throughout the recording.

5.5 Ear wise comparison for Meniere's disease group

In the present study, Meniere's disease group also showed no statistically significant difference between right and left ears. This can be attributed to the absent responses in 68% of the total MD group and also the individuals with unilateral MD failed to show significant difference between the affected ear and the unaffected ear. These findings could be due to a primary lesion in Meniere's disease on the saccule, damaging the neuroepithelium in the patient, which is enough to interfere with the generation or transmission of VEMP response. Rauch, Zhou, Kujawa, Guinan, and Herrmann (2006) compared VEMP responses between the unaffected and affected ears and reported that the VEMP responses in the affected ear were of

altered tuning and either elevated or absent responses. However, they have compared affected and unaffected ears and did not compare right/left differences.

5.6 Ear wise comparison for BPPV group

Previously, VEMP response was thought to be normal in BPPV patients (Heide et al, 1999); however, a study done by Welling, Parnes, O'Brien, Bakaletz, Brackmann, & Hinojosa (1997) indicates that the detachment of otoliths from the macula of the utricle is the suspected pathogenesis in BPPV and the degenerative process that affects the macula of the utricle might also affect the macula of the saccule, resulting in abnormal VEMP. *In the present study, BPPV group also showed no significant ear differences but descriptively there was difference in VEMP response between the ears. 7 out of eleven individuals had only unilateral responses and absent responses in the other ear. 3 individuals showed bilateral VEMP responses and also out of 3, 1 individual showed prolonged latencies and reduced amplitude.* This may be possibly due to significant effect of the pathology of BPPV affecting the saccular responses drastically only in one ear thereby causing the depletion of VEMP responses ipsilateral to the pathological saccular organ. Whereas, in few individuals the presence of VEMP responses from both ears may be attributed to the extent of saccular response affected can be of relatively lesser degree when compared to a unilateral saccular involvement. Hong, Park, Yeo and Cha (2008) reported abnormal VEMP responses recorded from the affected side when compared with their age-related control subgroup. So, it can be concluded that VEMP responses were either elevated or absent when recorded from the side affected by the pathology of BPPV. VEMP latencies were increased in BPPV patients, which may signify neuronal degenerative changes in the macula of the saccule. When an extensive neuronal damage was suspected by VEMP results such as "no response" in VEMP, the disease progress can be at a chronic and resistive course.

5.7 Comparison of VEMP responses across the three groups

When the VEMP responses recorded from individuals with normal auditory and vestibular functioning, individuals with MD and individuals with BPPV were compared there was a significant difference in the p13 and n23 latency and also the peak to peak amplitude across the groups was observed. Akkuzu, Akkuzzu, & Ozluoglu, (2006) also found similar results from their study by comparing VEMP responses from individuals with MD and BPPV and concluded that there was a significant difference in the VEMP responses recorded from these two clinical groups. Hong et al. (2008) reported a significant different in VEMP abnormality rates among individuals with MD and BPPV. The authors suggest that the difference in VEMP response rates can be due to the extent of saccular degeneration in individuals with BPPV and MD.

The latency of the first positive peak p13 obtained from the individuals with normal auditory and vestibular functioning group were significantly shorter than the individuals with MD and BPPV group. However, individuals with MD and BPPV group did not differ significantly in the p13 latency obtained. This is in contrary to Hong et al. (2008), according to them the prolongation of the p13 latency in BPPV group helped in differentiating from the MD and vestibular neuritis group.

The present study also showed n23 latency for BPPV group was significantly different when compared with either normal or MD group. There was no significant difference in peak to peak amplitude observed between MD group and BPPV group. Hong et al (2008) also concluded that the VEMP amplitude was higher in BPPV group than the MD and vestibular neuritis group and normals had the highest amplitude. The difference in the prolongation VEMP in individuals with BPPV can be attributed to the direct involvement of the saccular maculae whereas in the MD group the hydrops could have been confined only to the cochlea thereby affecting the sound transmission to the saccule but not affecting the physiology of saccule directly (Welling et al, 1997 & Hong et al, 2008).

5.8 Inter aural amplitude difference ratio (IADR)

The mean IADR of MD group (0.3775±0.17) was greater than the IADR of normal group (0.1578±0.22). This result was in accordance with the study done by Young, Huang and Cheng (2003). They studied the IADR and grouped the MD individuals into different stages. They grouped individuals with MD with an IADR of 0.30±0.30 into Stage III, which is characterized by a depressed or absent VEMP responses and also flat audiometric configuration. The authors reported that the VEMPs were normal in 5 (83%) of the stage I ears, indicating that the sacculocollic reflex retains normal velocity conduction in the earliest stage of Ménière's disease. Because VEMP amplitude has been correlated to the intensity of acoustic stimulation (Lim, Clouston, Sheean, Yiannikas, 1995 & Young, Wu, & Wu, 2002) augmented VEMPs can be explained as dilatation of the saccular hydrops extending to press against the footplate (Fraysse, Alonso, & House 1980), as this action enhances the sensitivity of the saccular macula to loud sound. A dilated saccule with an atrophied saccular macula, which was described in one histopathologic study of Meniere's disease (Schuknecht & Gulya, 1983), could be an explanation for depressed VEMPs which supports the results of the present study. So, the increased IADR in the MD group can be attributed to the presence of an atrophied macula.

Okuno and Sando (1987) suggested that the severity of hydrops correlates to the severity of hearing loss. Young, Huang, & Cheng, (2003) reported that the IAD ratio of the VEMPs increased significantly according to the stage of Meniere's disease. Therefore, the IAD ratio of VEMPs, like the 4-tone average of hearing, shows promise in facilitating the staging of Meniere's disease. In other words, besides the hearing test, the VEMP test provides another aid for evaluating the stage of Meniere's disease.

Osei-Lah, Ceranic, & Luxon (2008) distinguished acute and stable Meniere's disease using VEMP responses. According to them, the parameter that best differentiated acute from stable Meniere's disease at threshold was the interaural amplitude difference ratio. Therefore, this

parameter may be used to monitor the clinical course of Meniere's disease and its effect on the underlying physiological responses.

5.9 Ear effect in Meniere's disease group

In the present study, the VEMP responses recorded in individuals with unilateral MD showed either prolonged latencies with reduced amplitude or absent responses in the affected side. But the unaffected side showed VEMP responses in all of the recorded ears. This difference among the unaffected and the affected ears were not statistically significant but descriptively the latency was relatively shorter in the unaffected side. Also, the peak to peak amplitude was relatively greater in the unaffected side.

Again this can be attributed to the involvement of the saccular hydrops in the affected side which alters the normal physiology of the saccular maculae thereby affecting the recording of VEMP responses. A recent study compared VEMP in patients with Vestibular Drop Attacks (VDA) and non-VDA secondary to MD and reported that the incidence of absent VEMP in the affected ear with VDA was significantly larger than that in the affected ear with non-VDA (Timmer et al., 2006). While their findings suggested that VDA could arise from damaged otolithic organs, their results did not reveal reversibility of damage or the possible existence of endolymphatic hydrops in the otolithic organ.

Rauch (2006) reported that the affected Meniere's ears had significantly prolonged vestibular evoked myogenic potential responses and there was less tuning apparent at 500 Hz. Unaffected ears of Meniere's subjects also showed significantly elevated vestibular evoked myogenic potential thresholds compared with normal subjects. They concluded that Meniere's ears display alterations in VEMP responses and tuning, supporting the hypothesis of altered saccular motion mechanics arising from hydropic distention. Unaffected ears of unilateral Meniere's subjects showed similar changes, though to a lesser degree. This finding may be

because of occult saccular hydrops in the asymptomatic ear or binaural interactions in the vestibular evoked myogenic potential otolith-cervical reflex arc. This is in contrary to the current findings.

Lin et al., (2006) observed VEMP response in the asymptomatic ear of patients with unilateral MD. The client with unilateral MD showed elevated mean VEMP responses and altered VEMP tuning in their symptomatic ears and, to a lesser degree, in their asymptomatic ears. Thus, VEMP may be useful as a detector of asymptomatic saccular hydrops and as a predictor of evolving bilateral MD.

6. Summary and Conclusion

Vestibular evoked myogenic potential (VEMP) is an electromyographic response to loud auditory stimuli that is recorded in the sternocleidomastoid muscle during tonic contraction. The VEMP responses were first reported by Geisler, Frishkopf, and Rosenblith (1958) and identified by Bickford, Jacobson, and Cody (1964). It is used as a clinical test for the assessment of vestibular system by providing information on otolith function and the functional integrity of the inferior vestibular nerve (Zhou, and Cox, 2004).

The common pathological conditions which impact the normal functioning of the vestibular organs are Meniere's disease (MD) and Benign Paroxysmal Positional vertigo (BPPV). Since these conditions reveals with analogous signs and symptoms, the differential diagnosis of these two conditions is the capital need of the hour. The VEMP has been taken as a reliable clinical tool in the present study which was aimed:-

- To identify the pattern of VEMP responses in individuals with normal auditory and vestibular functioning, individuals with MD and in individuals with BPPV.
- To check for ear wise differences for the three groups.
- To compare the parameters of VEMP responses between the groups.
- To compare the interaural amplitude difference ratio (IADR) across the groups.
- To check for ear effect in VEMP responses for individuals with unilateral MD.

A total of 75 ears of 43 subjects were taken for the study. They were divided into three groups. Group I consisted of 33 ears of 20 individuals with normal hearing sensitivity without vestibular symptoms served as the control; group II consisted of 22 ears of 12 individuals who were diagnosed as having Meniere's Disease out of which four of them had unilateral MD, and group III consisted of 21 ears of 11 individuals who were diagnosed as having BPPV by an otologist.

Auditory brainstem response (ABR) was recorded for all the groups to rule out presence of retro cochlear pathology. The ipsilateral VEMP responses were recorded in both the ears using 500 Hz tone burst presented at 95 dB nHL for all the individuals. Using the protocol given by Damen (2007), the VEMP responses were recorded twice to check for its reliability and shown to three audiologists independently to identify the VEMP waves. The p13 and n23 peak latency and also the peak to peak amplitude were noted if there was agreement in identifying peaks among the audiologists. The latencies, amplitude and interaural amplitude difference ratio (IADR) and also the ear wise comparisons were analyzed using statistical package for social sciences (SPSS) software, version 16.

The following statistical procedures were carried out within and across each group of subjects:

- Descriptive statistics was performed to obtain the mean and standard deviation for all the parameters of VEMP.
- Multivariate Analysis of Variance (MANOVA) was done to check for significant differences in the VEMP parameters across the groups.
- Duncan's test to analyze which parameter was significantly different across the groups.
- Kruskal wallis test to cross check duncan's test, since the sample size were uneven across the groups.

- Mann Whitney U test was done to compare the Inter aural amplitude difference ratio (IADR) across the groups.
- Paired t-test was done to check for ear differences in VEMP parameters for individuals with normal hearing sensitivity and no vestibular symptoms.
- Wilcoxon's signed ranks test was done to see for ear differences in the parameters of VEMP for individuals with Meniere's disease (Group II) and individuals with benign paroxysmal positional vertigo (Group III) respectively.

The results of the statistical analysis revealed the following:

- The VEMP responses were recorded from all the individuals with normal auditory and vestibular functioning. Whereas, the VEMP response rate was least for individuals with MD. This can be due to the effect of hydrops on the cochlear mechanism which hinders the efficient sound transmission to the saccular maculae and also due to altered saccular motion mechanics arising from hydropic distention.
- The ear wise comparison across the groups revealed that there was no significant difference among the VEMP responses recorded from right and left ear for all the groups. But descriptively, the MD and BPPV group showed absent or prolonged VEMP responses which can be due to the pathologies affecting the normal saccular functioning.
- The group wise comparison of the VEMP parameters showed that there was a significant difference in the p13 and n23 latency of normal group and the groups with vestibular disorder. Between the MD group and BPPV there was no significant difference. The n23 latency of the individuals with normal auditory and vestibular functioning group and the MD group was significant different from the BPPV group. This can be attributed to the direct involvement of the saccular maculae whereas, in the MD group the hydrops could have been confined only to the cochlea thereby affecting the sound transmission to

the saccule but not affecting the physiology of saccule directly. There was no significant difference between the individuals with normal auditory and vestibular functioning group and the MD group. The peak to peak amplitude of the individuals with normal auditory and vestibular functioning group was significantly different from the group with vestibular disorders.

- The IADR of the MD group was significantly higher than that of individuals with normal auditory and vestibular functioning group. This can be due to the presence of atrophied saccular maculae thereby altering the VEMP response amplitude.

- The ear wise comparison of the unilateral MD group showed no statistically significant difference but descriptively, the responses from the affected side were either absent or prolonged when compared to the responses from the unaffected side. This finding may be because of occult saccular hydrops in the asymptomatic ear or binaural interactions in the vestibular evoked myogenic potential otolith-cervical reflex arc.

Conclusion:

The present study aimed at differentiating Meniere's disease and benign paroxysmal positional vertigo based on VEMP results. The VEMP response rates of the MD group were the least among the groups. There was a significant difference in the latency of p13 and n23 and also the peak to peak amplitude across the groups. The p13 latency of MD and the BPPV group were comparable whereas the n23 latency of the BPPV group was significantly prolonged than the MD group. There was difference in the VEMP responses of MD and BPPV group between the ears descriptively but statistically it was not significant. The Interaural amplitude difference ratio was significantly higher in MD group. Descriptively, there was a difference in the VEMP responses between the unaffected and affected side in individuals with unilateral MD. Thus, the IADR value could be used to identify individuals with MD.

Implications of the study

- The peak latency and the amplitude data can be used as normative for future research and clinical evaluation.
- The VEMP response rate, peak latencies, IADR can be used as reliable tools to differentially diagnose between MD and BPPV.
- The results can be added to the current literature in the evaluation of vestibular disorders using VEMP.

Core of future research

- VEMP thresholds can be obtained in individuals with MD and BPPV in Indian population.
- Tuning of VEMP responses in individuals with MD and BPPV can be measured.
- VEMP responses from age matched individuals with MD and BPPV can give more reliable data.
- Individuals with Meniere's disease can be staged using the IADR in Indian population.
- Ear effect in individuals with MD and BPPV can be assessed using a larger population.
- VEMP responses of MD can be compared with VEMP recorded from other conditions like Noise Induced Hearing loss (NIHL), wherein cochlea is affected in both these conditions.
- VEMP responses of BPPV can be compared with vestibular neuritis and also superior canal dehiscence.

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