EFFECT OF AGEING ON

VESTIBULAR EVOKED MYOGENIC POTENTIAL

Vivek (Mandal)
Register No: 08AUD033

A Dissertation Submitted in Part Fulfillment of Final Year

Master of Science (Audiology)

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ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MANASANGOTHRI, MYSORE – 570 006

May 2010

Dedicated to

GOD

My Dear ...

Father

Mother

Sister

&

Animesh Sir

Who taught me the Real meaning of

Life.....

CERTIFICATE

This is to certify that this dissertation entitled ***"Effect of ageing on vestibular evoked myogenic potential"*** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No. : 08AUD033. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Dr. Vijayalakshmi Basavaraj

Director

All India Institute of Speech and Hearing,

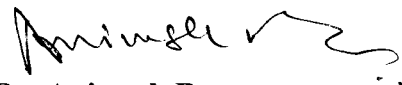
Manasagangothri, Mysore-570 006

Mysore

May, 2010

CERTIFICATE

This is to certify that the dissertation entitled ***"Effect of ageing on vestibular evoked myogenic potential"*** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier in any other University for the award of any Diploma or Degree.



Dr. Animesh Barman

Guide

Reader in Audiology,

Department of Audiology,

All India Institute of Speech and Hearing,

Manasagangothri, Mysore - 570 006.

Mysore

May, 2010

DECLARATION

This is to certify that this Master's dissertation entitled ***"Effect of ageing on vestibular evoked myogenic potential"*** is the result of my own study under the guidance of Dr. Animesh Barman, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted in any other University for the award of any Diploma or Degree.

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May, 2010

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Dream as if you'll live forever, live as if you'll die today.

!!! NEVER LOOSE THE END !!!

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Chapter 1

Introduction

Vestibular evoked myogenic potential (VEMP) testing is currently utilized in the assessment of variety of vestibular etiologies. The VEMP response is obtained by measuring the release of the sternocleidomastoid (SCM) muscle from a contracted state provoked by delivering auditory stimuli to the ipsilateral ear (Colebatch, Halmagyi, & Skuse, 1994). VEMP responses are considered to be a reflection of vestibulospinal projections to the neck, which give rise to information regarding saccule and inferior vestibular nerve integrity (Colebatch & Halmagyi, 1992; Robertson & Ireland, 1995). The pathway of the VEMP response is projected from the saccule and extends along the inferior branch of the vestibular nerve to the vestibular nuclei and project to motor neurons in the SCM muscle causing a release from the contracted state (Colebatch & Halmagyi, 1992; Colebatch et al., 1994; Halmagyi & Colebatch, 1995; Robertson & Ireland, 1995).

This reflex pathway was originally studied in animal models, which indicated afferent vestibular hair cells in the saccule to be responsive to click and tonal auditory stimulation at high intensity levels in cats and guinea pigs (Didier & Cazals, 1989; McCue & Guinan, 1994; McCue & Guinan, 1997; Merchant, 1999). Auditory sensitive neurons have also been located in the lateral and descending vestibular nuclei of guinea pigs (Merchant, 1999). These afferent vestibular hair cells of the saccule have been found to have an increased firing rate in response to toneburst and click stimuli above 90 dB SPL in cats (McCue & Guinan, 1994). Further research indicated these fibers to be most responsive to frequencies between 500 and 1000 Hz,

with little to no responsiveness occurring to auditory stimuli above 3000 Hz (McCue & Guinan, 1997).

Likewise, the VEMP response in humans has been found to be present at high presentation levels. VEMP thresholds have been reported to be between 120–135 dB SPL (Welgampola & Colebatch, 2001a) and 75–105 dB nHL (Ochi & Ohashi, 2003) in response to click stimuli, 105–120 dB SPL in response to 1000 Hz toneburst stimuli (Welgampola & Colebatch, 2001a) and 60 to 75 dB nHL in response to 250 Hz toneburst stimuli (Zapala & Brey, 2004). Like the animal models, VEMP responses in humans have been found to show optimal frequency sensitivity. Optimal stimulus frequencies have been reported to be 300–350 Hz (Todd, Cody, & Banks, 2000), 500 Hz (Rauch, Zhou, Kujawa, Guinan , & Herrmann, 2004) and 700 Hz (Welgampola & Colebatch, 2001a) in normal subjects.

The VEMP waveform consists of an early positive-negative component that occurs at 13 ms to 23 ms (p13-n23 or P1-N1) and a later negative-positive component that occurs at 34 ms to 44 ms (n34-p44 or N3-P4) (Colebatch & Halmagyi, 1992). The early component of the VEMP depends on the integrity of vestibular afferents as the response is abolished after vestibular nerve section but preserved in subjects with severe-to-profound sensori-neural hearing loss (Colebatch et al., 1994). It has been hypothesized that the later component of VEMP is mediated by cochlear afferents (Colebatch & Halmagyi, 1992), although recent evidence suggests that the source of the later components of VEMP has not been delineated yet (Wu & Young, 2002).

VEMP can be performed in a relatively short time and requires only equipment to test auditory brainstem responses (Lee, Cha, Jung, Park, & Yeo, 2008). Although VEMP results are dependent on many factors, it remains the most useful

and convenient method for separately evaluating the function of the inferior vestibular nerve. In addition, VEMP can be used to evaluate the function of the peripheral vestibular nerve, as well as central lesions in the vestibule-spinal tract (Lee et al., 2008).

Factors that can affect the VEMP results are: stimulus intensity, response laterality, muscular tonicity, condition of the middle ear cavity, patient age, and examination position (Wang & Young, 2006). Head elevation with rotation in the supine position requires more muscular strength to maintain during examination; thus, due to muscle fatigue, only low amplitudes VEMP can be measured (Park et al., 2001). For this reason, many laboratories used the method involving head rotation in the sitting position to induce contraction of the SCM (Lee et al., 2008).

Kelsch, Schaefer, and Esquivel (2006) were able to record VEMPs in normal hearing children age ranging from 3 to 11 years. A comparison of VEMP characteristics between newborns and adults revealed an increased P1 latency, shorter P1-N1 intervals, and smaller P1-N1 amplitudes in the newborns (Chen, Wang, Wang, Hsieh, & Young, 2007). The mean N1 latencies reported for infants and young children 3 to 5 years of age were shorter compared to adults (Kelsch et al., 2006; Sheykholeslami, Megerian, Arnold, & Kaga, 2005).

Patients with Tullio phenomenon typically have VEMP thresholds at levels 20-30 dB lower than normals (Bronstein et al., 1995; Colebatch et al., 1998). The most common abnormality associated with Tullio phenomenon is superior semicircular canal dehiscence (Minor, 2005; Watson, Halmagyi, & Colebatch, 2000).

Jonsson, Sixt , Landahl, and Rosenhall (2004) found that the overall prevalence of balance problems at age 70 was 36% in women and 29% in men.

Balance symptoms were more common among women than men, and increased with increasing age. At ages 88-90 years the corresponding values were 51-45%. Compared to younger persons, dizziness in older people is not only more common but it is also more persistent and is more incapacitating (Davis, 1994). The prevalence of dizziness increased with age and was higher in women but these differences were not statistically significant (Colledge, Wilson, Macintyre, & MacLennan, 1994)

Su, Haung, Young, and Cheng (2004) showed that as age increased over 60 years, the VEMP response rate decreased dramatically, while age increased, the VEMP amplitude decreased in comparison to n23 latency prolonged. Lee et al. (2008) observed that VEMP amplitude decreased with increasing age, which may be caused by a decrease in cervical muscle tonicity with aging and both p13 and n23 latencies were prolonged with age.

Need For the Study

Age-related morphological changes affecting the vestibular system from the end organs to the central nuclei are well documented. The vestibular epithelium shows hair cell loss of 6% per decade between the ages of 40 and 90 years (Rosenhall, 1973). Bergstrom (1973) reported a decrease in the number of vestibular nerve fibres by 5.5% per decade over a similar age range. Richter (1980) reported a decrease in hair cell density from the age of 30 years onwards with similar degrees of degeneration in all vestibular end organs.

Johnsson and Hawkins (1972) reported a loss of otoconia from the age of 30 onwards, affecting the saccule more severely than the utricle. A decrease in the number of thick myelinated primary vestibular afferents from the age of 40 with a 37% reduction in fibre counts in subjects aged 70–85 years has also been described

(Bergstrom, 1973). The vestibular nuclear complex shows an age related neuronal loss of 3% per decade from the age of 40, affecting all 4 nuclei (Lopez, Honrubia, & Baloh, 1997). Thus, age-related degeneration affects the pathways mediating vestibular reflexes at multiple levels. It is thus essential to have database for VEMP responses in elderly to differentiate pathological condition from normal degeneration processes.

Current investigations have documented age related changes in the VEMP response (Basta, Todt, & Ernst, 2005, 2006; Lee et al., 2008; Ochi &Ohashi, 2003; Su et al., 2004; Welgampola and Colebatch, 2001b; Zapala & Brey, 2004). Research indicates a decrease in VEMP amplitude and an increase in VEMP threshold with increased age (Basta et al., 2005, 2006; Lee et al., 2008; Ochi & Ohashi, 2003; Su et al., 2004; Welgampola & Colebatch, 2001b; Zapala & Brey, 2004). The amplitude of the VEMP response is contingent upon the degree of SCM muscle contraction (Akin et al., 2004; Colebatch et al., 1994).

Thus, the review suggests that with the ageing there would be change in VEMP responses. Assessing age related changes in VEMP responses must compare responses among populations with a uniform means of SCM muscle contraction. It is essential to carry out study across different age groups to observe age-related changes that might contribute to disequilibrium in older subjects. Secondly, most of the study was carried out to observe age related changes have taken discrete age group. Whereas, a reference study on continuous age group in elderly is essential to observe age related changes. Some of them used either tone burst or click to study age related changes on VEMP. However, the current study is taken up to observe effect of age on VEMP responses by taking a most effective tone burst (Rauch et al., 2004). The

current study also aimed to understand better about the exact age where significant changes can be noticed. Thus, the current study has been taken up, with the following aim.

Aim of the study

The aim of the study was to:

- Observe age related changes in VEMP results, and establish database for VEMP responses in elderly population.
- Know the age at which significant changes can occur, and
- Check for the ear wise differences in VEMP responses across the groups.

Chapter 2

Review of Literature

Clinical tools for diagnosing vestibular disorders caused by semicircular canal dysfunction are readily available, while tests sensitive to otolith disorders are scarce. During the past few years, there have been studies on vestibular evoked myogenic potentials (VEMPs) in animals and humans. It is thought that VEMPs have a vestibular origin. Thus, VEMP testing may provide a useful, non-invasive method for assessment of otolith function and the functional integrity of the inferior vestibular nerve (Akin, Murnane, & Proffitt, 2003; Chen, Young, & Wu, 2000; Colebatch, Halmagyi, & Skuse, 1994; Ferber-Viart, Duclaux, Colleaux, & Dubreuil, 1997; Ochi, Ohashi, & Nishino, 2001; Welgampola & Colebatch, 2001).

VEMPs are short latency electromyograms (EMG) that are evoked by high-level acoustic stimuli and are recorded from surface electrodes over the tonically contracted sternocleidomastoid (SCM) muscle. The neurophysiological and clinical data indicate that VEMPs are mediated by a pathway that includes the saccular macula, inferior vestibular nerve, the lateral vestibular nucleus, the lateral vestibulospinal tract, and the motor neurons of the ipsilateral SCM muscle (Halmagyi & Curthoys, 2000).

History

The early work of the Italian physiologist, Tullio (1929), laid the groundwork for the study of the acoustic sensitivity of the vestibular system. His work involved detailed observations of sound-evoked head movements, eye movements, and postural changes in alert animals following the surgical fenestration of various portions of the bony labyrinth.

Bekesy (1935), who won the noble prize in 1961, was the first to report vestibular responses to sound in normal human subjects and provided evidence that the responses were not mediated by the cochlea. He described small head movements toward the stimulated ear following the presentation of high level (122-134 dB SPL), 1000Hz tone and suggested the responses might have been the result of otolith organ stimulation via fluid displacement.

The first electrical responses to sound from the vestibular system were recorded in the pigeon by De Vries and Bleeker (1949). Bickford, Jacobson, and Cody (1964) recorded a short latency (onset of 6 to 8 msec) evoked potential over the inion in normal human subjects in response to high-level clicks. They showed that the response was generated by the electromyography (EMG) of neck muscles. The amplitude of such responses was proportional to stimulus level and tonic EMG level. The myogenic origin of the response was confirmed as it was abolished during relaxation of the neck musculature or following curarization.

Colebatch and Halmagyi (1992) recorded a myogenic response to high level, air conduction click stimuli using surface electrodes located over the tonically contracted sternocleidomastoid (SCM) muscle in human subjects. They coined the term "Vestibular Evoked Myogenic Potential" or "VEMP" to describe the response.

Wave Pattern

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 majority of normal participants (Basta et al., 2005; Maes et al., 2008; Versino, Colnaghi, Callieco, & Cosi, 2001; Wang & Young, 2003). Additional potentials such as n34–p44 may follow but are not present in all normal participants. Colebatch et al. (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.

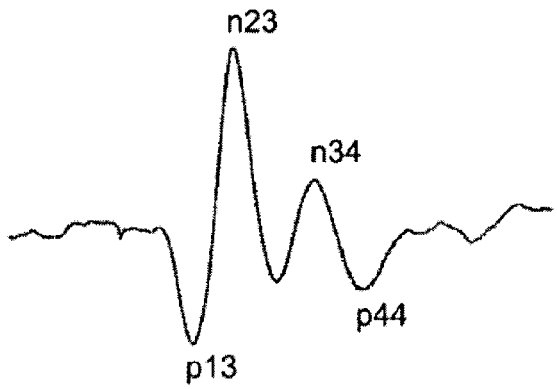

Figure 2.1: The VEMP response consists of an early and later biphasic positive-negative component.

The early positive-negative component is dependent on the integrity of vestibular afferents as it is abolished after vestibular nerve section but preserved in subjects with severe-to-profound sensorineural hearing loss (Colebatch & Halmagyi, 1992). Conversely, the later negative-positive component appears to be mediated by cochlear afferents (Colebatch et al., 1994) although recent evidence suggests that the source of the later component has not been delineated (Wu &Young, 2002).

Anatomy and Physiology

From the evolutionary point of view, the cochlear portion of the membranous labyrinth develops later 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, Guilhaume, & Aurousseau, 1983; McCue & Guinan, 1995; Young, Fernandez, & Goldberg, 1977).

In 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 et al., 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 i.e. hair cells (Zhou & Cox, 2004).

VEMP responses are considered to be a reflection of vestibulospinal projections to the neck, which give rise to information regarding saccule and inferior vestibular nerve integrity (Colebatch & Halmagyi, 1992; Robertson & Ireland, 1995). The pathway of the VEMP response is projected to begin in the saccule and extend along the inferior branch of the vestibular nerve to the vestibular nuclei and project to motor neurons in the SCM muscle causing a release from the contracted state (Colebatch & Halmagyi, 1992; Colebatch et al., 1994; Halmagyi & Colebatch, 1995; Robertson & Ireland, 1995).

This reflex pathway was originally studied in animal models, which indicated afferent vestibular hair cells in the saccule to be responsive to click and tonal auditory

stimulation at high intensity levels in cats and guinea pigs (Didier & Cazals, 1989; McCue & Guinan, 1994; McCue & Guinan, 1997; Merchant, 1999).

Afferent Pathways

Given that VEMPs are assumed to be of vestibular origin, several works have been assigned for the study of changes in responses in cases of specific impairment of the labyrinth or of the vestibular nerve.

Neurosensory deafness

Bickford, Jacobson, and Cody (1964) obtained a normal response from both the normal and the deaf ear in a patient with complete unilateral neurosensory deafness but with normal labyrinth. In a patient with unilateral neurosensory deafness and loss of labyrinthine function, however, responses were absent from the affected ear. These results suggest that response to sound-click was initiated via the vestibular system rather than the cochlear one.

Colebatch et al. (1994) studied three patients with severe unilateral sensory deafness but normal caloric testing. All of them had p13-n23 responses following stimulation of the affected ear, suggesting that the p13-n23 component of the response was of labyrinthine origin.

Vestibular defects

Townsend and Cody (1971) studied patients with bilateral vestibular neuronitis but normal hearing: no inion response was obtained from either ear. These observations confirm Cody and Bickford's hypothesis (1969) that inion response depends on the integrity of the vestibule.

Conversely, responses were recorded symmetrically on sternomastoid muscles (SM) and trapezius (TRP) in the case of vestibular nerve section with preservation of

cochlea and cochlear nerve; in contrast, responses are always abolished following total destruction of the cochlea and the vestibule (Ferber-Viart , Dubreuil , Duclaux , & Collet , 1995). It can be suggested from these results that responses could involve both receptors: the cochlea and the vestibule.

Vestibular nerve lesions

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–n23 originates from the saccule and may travel along the inferior vestibular nerve to the vestibular nuclei. A later study by Murofushi, Matsuzaki, and Mizuno (1998) supported this hypothesis where VEMPs were recorded in patients with vestibular schwannoma. These authors found that the p13–n23 was present only on the unaffected side. Conversely, on the affected side, the response was either absent or significantly decreased in amplitude.

Efferent 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 et al.(1994) proposed the LVST to be the efferent pathway of VEMPs based on existing evidence from published animal studies.

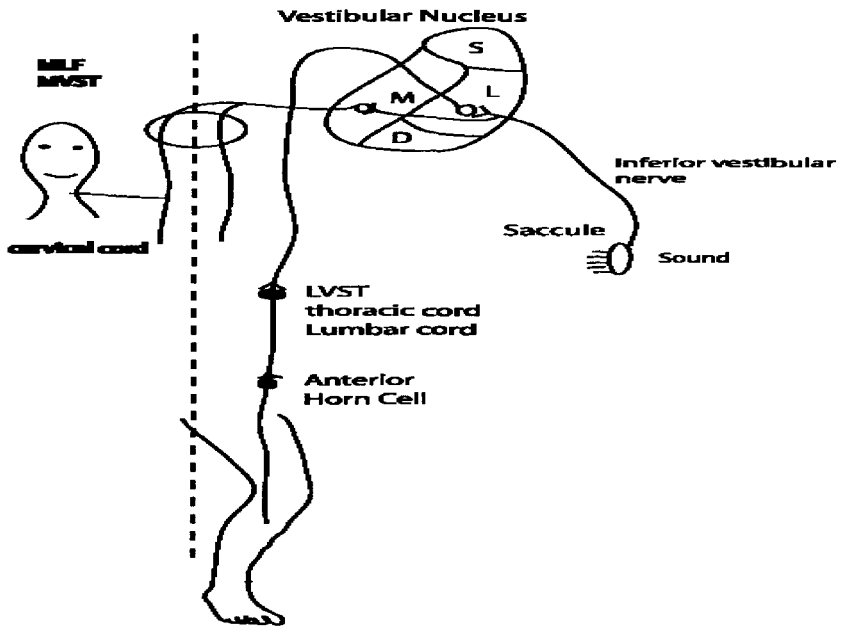

Figure 2.2: VEMP neural pathway.

Applications of VEMP

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). By adding VEMP measurements, the clinician may have the capability of revealing disorders in the saccule and/or inferior vestibular nerve (Zhou & Cox, 2004).

The VEMPs are suitable for clinical application for the following reasons:

- The response, specifically the first wave (p13–n13), is repeatable and consistent. Despite variations in amplitude, the latency is relatively stable.
- 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.
- Potentially, VEMP testing could be sensitive and able to detect minor changes in the function of the vestibular system.
- 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. VEMP testing takes less than an hour. VEMP testing may provide valuable information in diagnosis of the following disorders:

Vestibular

Vestibular Neuritis

Ochi, Okashi and Watnabe (2003) observed abnormal VEMP in two of the eight patients with unilateral vestibular neuritis. Absence of VEMP is reported in patients with vestibular neurolabyrynthitis which indicates the involvement of inferior vestibular nerve (Murofushi, Halmagi, Yavor & Colebatch, 1996).

Meniere's disease

Clinical studies have found that VEMPs are present in 46 to 100% of patients with Meniere's disease (Seo, Node, Yukimas & Sakagami, 2003; Young, Wu, & Wu, 2002). Young et al. (2002) described abnormally large amplitude in the suspected ear in three patients with unilateral endolymphatic hydrops.

When VEMPs were recorded during Meniere's attack, Kuo, Yang, and Young (2005) found that the response was absent in 67% of patients suggesting a saccular involvement. VEMP returned to normal in half of these patients and the change in response was attributed to reduction in saccular hydrops. Seo et al. (2003) observed that VEMP amplitude increased in 40% of the Meniere's ears following Furosemide injection with VEMPs appearing in some ears following an absent response at pre-furosemide testing.

Tullio Phenomenon

Patients with Tullio phenomenon typically have VEMP thresholds at levels 20-30 dB lower than normals (Bronstein et al., 1995; Colebatch et al., 1998). However, the most common abnormality associated with Tullio phenomenon is superior semicircular canal dehiscence (Minor, 2005; Watson et al., 2000).

Superior Semicircular Canal Dehiscence (SSCD)

Struebel at al. (2001), have studied VEMP responses in subjects with Superior Canal Dehiscence and found lowered VEMP thresholds in these subjects and concluded that VEMP can be included in the test battery along with symptoms, signs and CT imaging in diagnosis of Superior Canal Dehiscence syndrome. Brantberg, Bergenius, and Tribukait (1999) found low threshold for VEMP responses especially in the frequency range of 0.5 – 1 KHz in 3 patients with Superior Canal Dehiscence.

Vestibular Neuromma

Murofushi, Matsuzaki, and Mizuno (1998) reported abnormal VEMPs in 80% of 17 patients with vestibular schwannoma. In another study done by Matsuzaki, Murofushi, and Mizuno (1999), observed abnormal VEMPs in 2 patients with vestibular schwannoma while ABR data were normal.

Ochi, Oshashi, and Nishino (2001) reported 3 vestibular schwannoma cases with abnormal VEMPs, including elevated thresholds, abnormal interaural differences of thresholds, and abnormal p13–n23 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 tumour was located. Moreover, no correlation was found between the VEMPs and tumour size.

Benign Paroxysmal Positional Vertigo (BPPV)

Boleas-Aguirre, Sánchez-Ferrándiz, Artieda, and Pérez (2007) found a lack of VEMP response in 52 % of the ears with BPPV. Yang, Kim, 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. VEMP

latencies are increased in BPPV patients, which may signify neuronal degenerative changes in the macula of the saccule. Hong, Kim, Yeo, and Cha (2008) also found that the patients with BPPV may show abnormal VEMP findings, irrespective of the involved semicircular canal.

Auditory

Auditory Neuropathy

Sheykholeslami, Schmerber, Kermeny, and Kaga (2005) had recorded VEMP using tone burst in a case with bilateral auditory neuropathy (AN). There were no response on left ear stimulation and a biphasic response with normal latency and amplitude on right-ear stimulation.

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 VIII cranial nerve in a high percentage of the auditory neuropathy population.

Acoustic Neuroma

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

Conductive Hearing Loss

Interference of sound transmission due to some disorders such as chronic otitis media (COM) may lead to absent VEMPs (Young, Wu & Wu, 2002). Tone

stimuli rarely elicit VEMP responses in patients with conductive hearing loss (Halmagyi, Calebatch, & Curthoys, 1994). Yang and young (2003) found that 13 (59%) of the 22 ears showed positive VEMPs using the tone burst method whereas 20 ears (91%) displayed positive VEMPs by the tapping method. So they concluded that while stimulating, sound is attenuated by middle ear pathology. VEMPs are attenuated or absent in subjects with Otosclerosis (Halmagyi et al., 1994; Ochi, Ohashi, & Kinoshita, 2002).

Sudden Deafness

VEMPs were evoked by short tone burst, in 20 patients with unilateral idiopathic sudden deafness (Wu & Young, 2002). All the twenty deaf ears displayed normal biphasic VEMPs.

Sensorineural Hearing Loss

VEMP potential is independent of degree of sensory neural hearing loss as reported by Bickford et al. (1964); Colebatch et al. (1994); Rosengren and Colebatch (2006); Takegoshi and Murofushi (2003); Wu and Young (2002).

Ito, Ishimoto, and Murofushi (2001) reported the presence of VEMPs bilaterally in a patient with unilateral profound sensorineural hearing loss caused by extreme narrowing of the internal auditory meatus with absent or extremely thin cochlear nerve.

Wu and Young (2004) observed that VEMPs were present in most patients with low-frequency sensorineural hearing loss unrelated to Meniere's disease, but absent in approximately 50% of cases of low-frequency hearing loss related to Meniere's disease.

Noised Induced Hearing Loss (NIHL)

Wang, Hsu and Young (2006) investigated the VEMP responses in 20 patients (29 ears) with acute acoustic trauma and observed 18 ears presenting normal VEMPs. Wang and Young (2007) found that patients with bilateral 4 KHz notched audiogram and hearing threshold of 4 KHz $\geq$ 40 dB show abnormal VEMP, indicating that the vestibular parts, especially the sacculocollic reflex pathway, has also been damaged. Christiana, Bhat and Kumar (2008) reported that VEMP was either abnormal or absent in 67% of NIHL subjects.

Neurologic Pathologies

Multiple Sclerosis

The latencies of a vestibulospinal reflex can be prolonged in multiple sclerosis (Shimizu, Murofushi, Sakurai, & Halmagyi, 2000). Alpini, Pugnetti, Caputo, Cornedio, Capobianco, and Cesarani (2004) took 40 patients who were diagnosed with multiple sclerosis and they observed abnormal VEMPs, indicated brainstem dysfunction in 4 patients (10%) with normal MRI and no specific clinical signs.

Brainstem Lesions

Itoh et al. (2001) described VEMP abnormalities in patients with middle to lower brainstem lesions. VEMP abnormalities observed in these patients include absent responses, prolonged latencies, and elevated thresholds. VEMPs are often normal in patients with cerebellar strokes (Pollack, Kushnir, & Stryjer, 2006).

Factors affecting VEMP responses

A) Recording Site

In the study done by Bickford et al. (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 et al. (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. 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, 2001).

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 lower amplitudes, 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).

VEMP responses were also recorded from extra-ocular muscles using air-conducted 500 Hz tone burst. They are best recorded contralaterally on upgaze (Chihara, Ito, Sugasawa, & Shin, 2007).

B) Methods for recording VEMP

VEMP evoked by bone- conducted stimuli

Skull taps and bone-conducted tones are stimuli that by pass the middle ear. A forehead tap delivered at F_{pz} (international 10-20 system) via a tendon hammer, evokes a vestibular dependent short latency p13-n23 response in both SCMs. The tap also evokes a second negativity (n2), which can sometimes be difficult to separate from n23 and thus produces unambiguous analysis in some normal subjects (Halmagyi, Yavor, & Colebatch, 1995).

Tap-evoked VEMPs owing to the magnitude of the stimulus are 1.5 to 3 times as large as those evoked by clicks. These are relatively preserved in older subjects in whom stimulus thresholds are likely to be high (Welgampola & Calebatch, 2001).

A bone- conducted tone burst delivered over the mastoid process via a B71 clinical vibrator (radio ear corporation, Philadelphia, PA), routinely used in audiometric testing, evokes VEMPs despite conductive hearing losses (Sheykholeslami, Murofushi, Kermany, & Kaga, 2000; Welgampola, Rosengren, Halmagyi, & Colebatch, 2003). Optimum stimulation is delivered with the conductor placed 3 x 2cm posteriosuperior to the external acoustic meats, using frequencies of 200 to 250 Hz (Sheykholeslami et al., 2000; Welgampola et al., 2003).

VEMP evoked by galvanic simulation

A short duration (2 millisecond) pulsed current delivered via electrodes attached to the mastoid processes evokes a p13-n23 response on the side ipsilateral to cathodal stimulation. Similar to that evoked by sound stimuli of 4mA/2msec as used for clinical testing are well tolerated by patients. Such a current in close proximately to the recording site causes a large stimulus artifact and specific subtraction

techniques are required to recover the response of interest (Watson & Colebatch, 1998).

C) Stimulus related Factors

Frequency

Tone-evoked VEMP amplitudes were larger than click-evoked amplitudes when comparisons were made at equal peak SPLs (Akin et al., 2003). Welgampola and Colebatch (2001) reported that tone-burst evoked myogenic responses were similar to click-evoked responses but required lower stimulus intensities. The largest amplitudes and lowest thresholds were obtained at 500 and 750 Hz with the smallest amplitudes and highest thresholds recorded with 1500 and 2000 Hz tone bursts (Akin et al., 2003). Murofushi et al. (1999) observed larger VEMP amplitudes with 500Hz tone bursts than with 1000 and 2000Hz tone bursts. Welgampola and Colebatch (2001) reported largest VEMP amplitudes at 500 and 1000 Hz. Todd et al. (2000) recorded VEMPs with frequencies ranging from 100 to 3200 Hz and demonstrated a maximum in response amplitude ranging from 200 to 400 Hz, although stimulus frequencies between 400 and 800 Hz were not used. McCue and Guinan (1995) found that the inferior vestibular nerve fibers were responsive to sound with best frequencies between 500 and 1000Hz and threshold ranging from 90 to 115 dB SPL.

Stimulus Level

VEMP amplitude increases as there is corresponding increase in the stimulus level, a finding that has been observed in studies using both clicks (Akin et al., 2003; Colebatch et al., 1994; Ochi & Ohashi, 2003) and tone bursts (Akin et al., 2003). In contrast to VEMP amplitude, P1 and N1 latency do not vary as a function of stimulus level.

Repetition Rate

In consideration of the peak-to-peak amplitude, VEMPs for 1 Hz and 5 Hz stimuli showed the highest amplitude with a tendency to decrease progressively as repetition rate increases (Wu & Murofushi, 1999). The subject would need to contract the neck muscles longer if 1 Hz stimuli were used. Therefore 5 Hz to be the optimal stimulation rate for the clinical use of VEMP (Wu & Murofushi, 1999).

Ozeki, Iwasaki, and Murofushi (2005) had evaluated the influence of stimulation rate of galvanic on the galvanic evoked vestibulocollic reflexes and to propose the optimal stimulation rate for clinical use. Responses were evident in all 60 ears only at 5 Hz. The relative amplitudes in individual ears were higher at 1, 3, 5 Hz than at 7 and 9Hz.

Monaural Vs Binaural presentation

Binaural acoustic stimulation versus monaural stimulation can produce different results. 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 while testing old or disabled patients. However, recent studies (Akin et al., 2003; Murofushi, Ochiai, Ozeki, & Iwasaki, 2004) have shown that VEMPs are ipsilateral-dominant responses when SCM muscles are used as the recording site with unilateral acoustic stimulation.

Stimulus Duration

Haung, Su, and Cheng, (2005), studied the VEMP response evoked by various click durations (0.1 to 0.5ms) and found that 0.5ms duration of click elicits more prominent wave morphology, shorter interaural latency than any other duration. This suggests that 0.5ms is superior to other click durations in eliciting VEMP response for clinical use.

D) Subject Related Factor

Response laterality

Bickford, Jacobson, and Cody (1964) and Townsend and Cody (1971), observed symmetric responses from both sides. 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) 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. They also observed no significant left–right difference in amplitude under binaural stimulation. Murofushi et al. (2004) observed positive–negative biphasic responses on the ipsilateral SCM by clicks and tone-bursts rather than contra lateral.

Muscle Tension

Bickford et al. (1964) noticed that increased muscle tension in the neck muscle produced increases in amplitudes; while the intensity of stimuli remained unchanged. Colebatch et al. (1994) observed a linear relationship between the amplitude of the response and the mean level of EMG activity.

Gender Effects

No significant amplitude or threshold differences between male and female subjects have been observed (Akin et al., 2003; Ochi & Ohashi, 2003; Welgampola & Colebatch, 2001b). Gender related latency differences are less clear. Brantberg and Franson (2001) found that P1 latency was significantly earlier in females. Akin et al. (2003) and Basta et al. (2005) reported no latency difference between male and female subjects. In contrast Lee at al. (2008) reported that latencies were more prolonged in females and amplitude was higher in females than males.

Aging Effects

VEMP in Children

Kelsch, Schaefer and Esquivel (2006) were able to record VEMPs in normal hearing children age from 3 to 11 years. In newborns aged 2 to 5 days, Chen, Wang, Wang, Hsieh, and Young (2007) found that VEMPs were present in 40 %, prolonged in 35 %, and absent in 35 % of the ears tested and suggested that the results reflected variation in the maturation of the sacculo-collic reflex at birth. The Vestibulo collic reflex normalizes by 2 months of age and matures further till 2 yrs of life (Fife et al., 2000).

A comparison of VEMP characteristics between newborns and adults revealed an increased P1 latency, shorter P1-N1 intervals, and smaller P1-N1 amplitudes in the newborns (Chen et al., 2007). The mean N1 latencies reported for infants and young children 3 to 5 years of age were shorter compared to adults (Kelsch et al., 2006; Sheykholeslami et al., 2005).

Sheykholesami et al. (2005) had recorded VEMPs induced by air and bone conducted auditory stimuli. They observed that the neonatal had shorter latency of the n23 peak and had higher amplitude variability.

Structural changes of Vestibular system with Age

Evidence of age related degenerative changes affecting the vestibular system is well documented. Age-related degenerative changes can affect the vestibular system, from the end organs to the central nuclei (Lee et al., 2008).

Hair cell related

The vestibular epithelium shows hair cell loss of 6% per decade between the ages of 40 and 90 years (Rosenhall, 1973). Rosenhall (1973) reported hair cell loss of 40% in the cristae of the semicircular canals predominantly affecting type 1 cells and less pronounced losses of 24 and 21% in the saccular and utricular maculae in subjects over the age of 70 years.

Merchant et al. (2000) confirmed a similar pattern of loss with the cristae losing type 1 cells more rapidly with age than maculae. Richter (1980) reported a decrease in hair cell density from the age of 30 onwards with similar degrees of degeneration in all vestibular end organs.

Neural related

Bergstrom (1973) reported a decrease in the number of vestibular nerve fibres by 5.5% per decade between the ages of 40 and 90 years. A decrease with age in the number of cell bodies in Scarpa's ganglion (Richter, 1980) and a loss of neurons in the vestibular nuclear complex (Lopez, Honrubia, & Baloh, 1997) have been reported.

Johnsson and Hawkins (1972) reported a loss of otoconia from the age of 30 onwards, affecting the saccule more severely than the utricle. A decrease in the

number of thick myelinated primary vestibular afferents from the age of 40 with a 37% reduction in fibre counts in subjects aged 70–85 years has also been described (Bergstrom, 1973). The vestibular nuclear complex shows an age related neuronal loss of 3% per decade from the age of 40, affecting all 4 nuclei (Lopez et al., 1997). Thus, age-related degeneration affects the pathways mediating vestibular reflexes at multiple levels.

VEMP studies in Elderly

The click and galvanic evoked responses were present bilaterally in all subjects below 60 years of age. Average click evoked response amplitude decreased with age, with a pronounced decline of 25-30% per decade from the 6th decade. The average click thresholds increased from 85dBnHL in the third decade to 96.5dBnHL in the 8th and 9th decade for average galvanic evoked Vestibulocollic reflex (VCR) amplitude which decreased sharply from the seventh decade. Tap evoked reflex amplitudes showed a milder decrease. When side to side differences in amplitude were expressed as asymmetry ratios (AR) in subjects below the age of 60 years, values of up to 35 and 46% were obtained for click amplitudes correlated and un correlated for background electromyogram (EMG), up to 61% for both corrected and uncorrected tap response amplitudes, and up to 41 and 55% for corrected and uncorrected galvanic evoked responses. In conclusions click and galvanic evoked VCR amplitudes decreased rapidly thereafter while tap evoked responses are less affected. These changes are probably due to morphological changes in the vestibular system occurring with aging (Welgampola & Colebatch, 2001b).

Su, Haung, Young, and Cheng (2004) had investigated affect of age on VEMPs. Group I included patients aged<20years, Group II subjects age ranged from

21 to 40 years, Group III subjects were 41 to 60 years and group IV included subjects older than 60 years. Results showed that VEMP response rate from groups I to IV was 98%, 96%, 90%, and 60% respectively, with a significant difference only between group IV and other groups. The amplitude was negatively correlated with age in contrast to the n23 latency, correlating positively with age; both reaching a significant difference. Although the p13 latency had a trend to prolong as age increased, no significant correlation was noticed with age. As age increased over 60 years, the VEMP response rate decreased dramatically, while age increased, the VEMP amplitude decreased in comparison to n23 latency prolonged. These findings might suggest that aging could deteriorate the saccular and corresponding neural functions.

Tampas, Akin, Murnane, and Clinard (2006) investigated the influence of EMG level and aging on the VEMP. Both younger (22-30 years) and older subjects (≥ 65 years) were able to achieve target EMG levels of 30 and 50 μV during unilateral activation of the SCM muscle. However, the older subjects had more difficulty than younger subjects in achieving target levels greater than 50 μV. When VEMP amplitude was compared across groups at similar EMG levels (i.e., 30 and 50 μV) the older group exhibited significantly smaller amplitudes than the younger group. These findings suggest that the decrement in VEMP amplitude observed in subjects over the age of 60 are due to the degenerative effects of aging on the vestibular system rather than SCM muscle tone.

Lee, Cha, Jung, Park and Yeo (2008) studied affect of age on VEMPs. 97 (194 ears) subjects participated in the study. Subjects were divided by age into the following groups: group I, 10-19 years (n-13); group II, 20-29 years (n-17); group III, 30-39 years (n-14); group IV, 40-49 years (n-13); group V, 50-59 years (n-19); group

VI, 60-69 years (n-14); and group VII, 70-79 years (n-7). Results revealed that VEMP amplitude decreased with increasing age, which may be caused by a decrease in cervical muscle tonicity with aging. Both p13 and n23 latencies were prolonged with age. They concluded that the statistically significant correlations between vestibular evoked myogenic potential (VEMP) parameters and age may be due to hair cell loss of the otolith organ and/or to degenerative changes of the vestibular neural pathway. These findings indicate that age should be taken into account when interpreting VEMP results.

Basta, Todt and Ernst (2005, 2006) recorded air and bone conducted VEMP with a tone bust of 500 Hz. The latencies did not show any significant differences among the groups (group I: 20-40 years, group II: 41-60 years & group III: >60 years). The p1-n1 amplitudes were decreased with increasing age. The change in the amplitude was noted from 40 years. The most significant reduction in amplitude was observed from approximately the age of 60 years.

Brantberg, Granath and Schart (2007) obtained VEMP response using 500 Hz tone burst at 129 dB SPL. The study group consisted of 1000 consecutive patients between 7 to 91 years of age. The result revealed that VEMP amplitude seemed to decrease less with age among those younger than 30 years and there was prolongation for both p13 and n23 latency with increasing age.

Janky and Shepard (2009) studied to test the hypothesis that significant changes in VEMP responses occur as a function of age. Forty-six normal controls ranging between 20 and 76 years of age participated in the study. Participants were separated by decade into 5 age categories from 20 to 60 plus years. Result showed that VEMP thresholds increase with increased age. VEMP response rates also

decreased with increased age. They concluded that age should be taken into account when interpreting VEMP threshold.

It is evident from the review of literature that the latencies of P13 and N23 increase with age. However, there is scanty literature on age related changes on VEMP response on Indian population. So there is a need to have normative data in order to correctly characterize VEMP responses as a function of increasing age. Thus, it is essential to carry out study across different age groups to observe age-related changes that might contribute to disequilibrium in older subjects and to have baseline to compare the subjects with vestibular disorder to normal aging process.

Chapter 3

Method

The aim of the study was to observe the age related changes in VEMP and also to note age at which a significant change can be noticed. Five groups of participants were taken to arrive at the objectives.

Subjects

A total of 79 (145 ears) subjects participated in the study. They were divided into following five groups.

Group I: Consisted of 62 ears of 32 individuals. These individuals were between the age ranging from 20-30 years with a mean age of 22.55 years. 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. They served as the control group

Group II: Consisted of 26 ears of 14 individuals. These individuals were between the age ranging from 40 to 50 years with a mean age of 43.36 years.

Group III: This group had 20 ears from12 individuals. The mean age of this group was 53.75 years with an age range of 50 to 60 years.

Group IV: Consisted of 24 ears of 14 individuals. These individuals were between the age ranging from 60 to 70 years with a mean age of 64.57 years.

Group V: This group had 13 ears from 7 individuals. The mean age of this group was 76.57 years with an age range of 70 to 80 years.

In the present study participants of sensory-neural hearing loss of any degree (up to profound) were taken in group II, III, IV and V as Bickford et al. (1964); Colebatch et al. (1994); Rosengren and & Colebatch (2006); Takegoshi and

Murofushi (2003); Wu and Young (2002) reported that VEMP potential is independent of degree of sensory neural hearing loss.

Selection Criteria

All the subjects participated in the study fulfilled the following criteria.

- All the participants had uncomfortable level greater than 105 dB HL for Speech.
- All of them had 'A' type tympanogram with normal, elevated or absent acoustic reflexes.
- No history or presence of any middle ear pathology.
- Absence of space occupying lesions which was ruled out based on ABR test results and / or neurological reports.
- No history or presence of any observable neurological symptoms.
- They reported no complaints of giddiness, vertigo and balance problem.

Instrumentation

- A Calibrated diagnostic audiometer, Grason Stadler Inc-61 (GSI-61) used to obtain pure tone thresholds and uncomfortable loudness level.
- A Calibrated GSI Tympstar immittance meter was used for tympanometry and reflexometry.
- Intelligent hearing system (IHS version 3140) was used to tap both auditory brainstem responses and vestibular evoked myogenic potentials and Eartone 3A insert earphones to deliver the stimulus.

Test Environment

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

Procedure

The control group was selected for further evaluations by administering a detailed case history wherein the participants did not report of having hearing loss. All the participants of the study had neither history of nor presence of any middle ear pathology and no symptom related to vestibular dysfunction. Participants of group II, III, IV and V had hearing loss as one of the parameter that differed from the control group.

A detailed case history regarding vestibular system was obtained from all the subjects participated in the study. The IInd section of dizziness questionnaire developed at Maryland hearing and balance center was used which is given in appendix - A. The participants selected through the case history had undergone the following Audiological tests.

- *Pure tone audiometry*: the behavioural 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 modified Hughson and Westlake method (Carhart & Jerger, 1959).
- *Uncomfortable level*: was measured by presenting the speech material through the headphone (TDH-39) at different intensities using ascending method. The uncomfortable level for speech was the hearing level at which the participants considered speech material to be uncomfortably loud. This was done to rule out presence of recruitment and tolerance problem since the stimuli presented to record the evoked potentials were of higher intensity.

- *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. The participant was made to sit comfortably and was asked not to swallow during the testing period. Initially tympanometry and then acoustic reflex threshold was obtained for all the participants.
- *Auditory brainstem response*: were done to rule out retro-cochlear pathology involving auditory nerve for the subjects who had hearing loss less than 70 dBHL. The electrode sites were cleaned with the help of skin preparing gel. Electrodes were then placed on the recording site with the conduction paste and then fixed them with the help of surgical tape. 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/ sec	Electrode montage	Non-inverting : FPz Inverting : A1/A2 Ground : A2/A1
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 receiver	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 latencies were noted for ABR waveform, recorded at 11.1/ sec repetition rate and wave morphology and presence or absence of ABR waves were noted for 90.1/ sec to identify retro-cochlear pathology (RCP). Those who had normal inter wave latency at 11.1/sec and good morphology at 90.1/ sec, depending upon

their hearing sensitivity was considered as not having RCP and was included for the study.

Procedure used to record Vestibular Evoked Myogenic Potential

Subjects who fulfilled the selection criteria based on the case history and above mentioned audiological tests have undergone VEMP recording. The participants were placed in a comfortable environment, where the participants were made to sit on a reclining chair. The participants were asked to turn their head to opposite side of the ear being stimulated to tense the Sternocleidomastoid (SCM) muscle. While recording the VEMP, the tonic EMG level was maintained for each participant between 100 to 200 micro volts. A visual feedback which was available in the instrument was provided to each of the participant to monitor tonic EMG level of sternocleidomastoid muscle. They were instructed to avoid extraneous movements of head, neck and jaw while recording the VEMP.

Table 3.2: *Electrode Montage used to record VEMP*

Electrode montage	• Non-inverting electrode (+): Midpoint of the Sternocleidomastoid muscle of the side being stimulated. • Inverting electrode (-): Sternoclavicular junction. • Ground electrode: Forehead.

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. The protocol used to record VEMP is shown in table 3.3.

Table 3.3: *Protocol used to record VEMP*

Stimulus Parameters		Acquisition Parameters	
Stimulus	500 Hz Tone Burst	Mode	Ipsilateral
Duration	5000μs	Electrode type	Disc electrode
Stimulus rate	5.1 per sec	Amplification	5000
Polarity	Rarefaction	Analysis window	70 ms
No. of Sweeps	200	Filter settings	30 to 1500 Hz
Intensity	105 dBnHL & 70 dBnHL	Notch Filter	Off
Transducer	ER 3A Insert receiver	Impedance	Inter electrode: within 2 k ohm Intra electrode: < 5 k ohm

500Hz tone burst was taken to evoke VEMP as Akin, Murnane, and Proffitt (2003); Chihara, Ito, Sugasawa, and Shin (2007); Janky and Shepard (2009) observed that VEMP amplitude is more at 500 Hz than at any other frequency. Stimulus rate of 5 Hz was used as it showed the highest amplitude, and with a tendency to decrease progressively as repetition rate increases (Akin et al., 2003; Ozeki et al., 2005; Wu & Murofushi, 1999).

VEMP was recorded at 70 dBnHL to rule out the presence of artifact. Absent VEMP at 70 dBnHL was considered as absence of artifact.

Analysis

- Acoustically evoked VEMPs were recorded twice to check for its reliability and stored in a computer.
- 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 (P_{13}-N_{23}) amplitude were noted, if there was an agreement in identifying the peaks among the audiologists.
- 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.

Chapter 4

Result

The present study was taken up with the aim to observe the age related changes in VEMP waves and also to see age at which significant changes occur. There is a need to have data base in order to correctly characterize VEMP responses as a function of increasing age.

To accomplish the objectives, the latencies of p13, n23 and peak-to-peak amplitude of VEMP responses were noted. Comparison of VEMP latencies and amplitude across the five groups were carried out. Also ear-wise comparison for latencies and amplitude measures was done within and between the groups. The latencies and amplitude were analyzed using statistical package for social sciences (SPSS) software, version 16. The following statistical analyses were carried out within and across the groups of subjects:

- Descriptive statistics was done to obtain the mean and standard deviation for all the parameters of VEMP for all the groups.
- For group I to IV, Mixed analysis of variance (Mixed ANOVA) was done to check for significant differences in VEMP parameters between the ears and also across the groups.
- Duncan's Post Hoc test was administered to know, which two groups VEMP parameters significantly differ from each other, once the Mixed ANOVA showed significant interaction.
- To see ear-wise difference in VEMP parameters in group V, Wilcoxon's signed ranks test was administered as the sample size was small.

- Kruskal-Wallis test was done to cross check Mixed ANOVA test results, since the sample size was uneven across the groups (including group V).
- Mann-Whitney U test was done to check for significant differences in the VEMP parameters between any two groups, wherever Kruskal-Wallis test showed significant difference.

VEMP responses obtained in Group I

VEMP was recorded from 64 ears. Out of 64 ears 62 ears had VEMP responses. The percentage of occurrence of VEMP in Group I was about 96.88 %. Out of 62 ears, 6 ears showed noisy VEMP responses and had poor wave morphology. The VEMP response obtained from an individual with normal auditory and vestibular functioning is shown in the Figure 4.1.

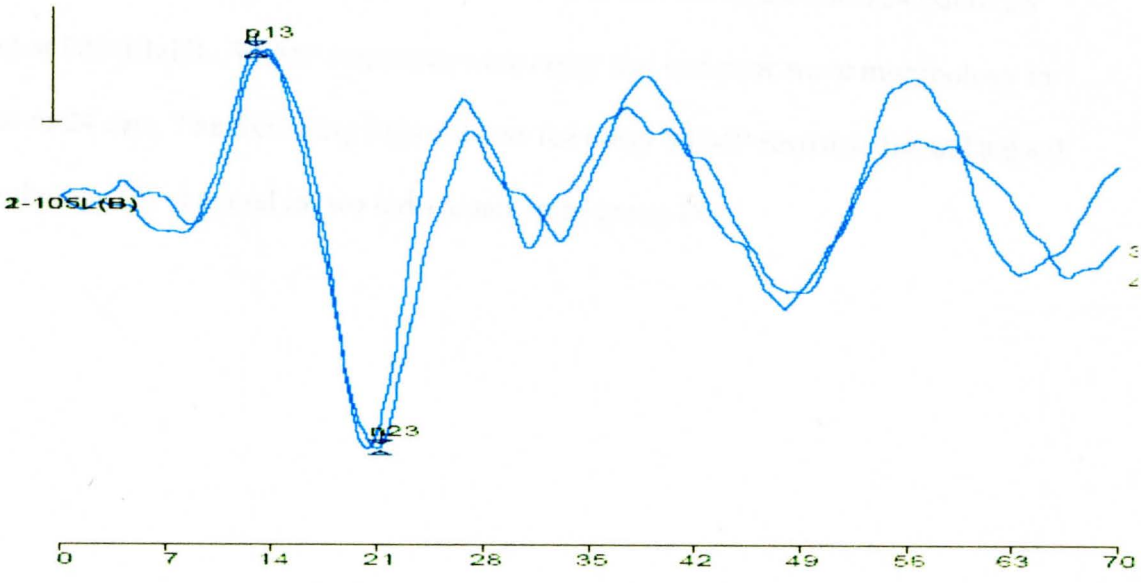

Figure 4.1: VEMP response showing p13 and n23 peaks recorded for 500 Hz tone burst presented at 105 dBnHL in an individual from group I.

VEMP responses observed in Group II

The VEMP was present in 26 ears out of 28 ears (92.85%) at 105 dBnHL. Out of 26 ears, 9 ears had noisy VEMP responses and poor wave morphology. Rest 17 ears had good wave morphology.

VEMP responses recorded in Group III

In this group VEMP was recorded from 24 ears. Out of 24 ears 20 ears had VEMP responses and 4 ears didn't have VEMP responses. Hence, the occurrence of VEMP response in this group was 83.33 %. A good VEMP wave morphology was recorded from 18 ears and two ears had noisy waveform.

VEMP responses recorded in Group IV

The VEMP responses could be recorded in 85.71% of the ears (24 out of 28 ears) at 105 dBnHL. VEMP responses were noisy and had poor wave morphology in 8 out of 24 ears. The following figure shows the noisy VEMP response (a) and a good morphology (b) obtained in two individuals from group IV.

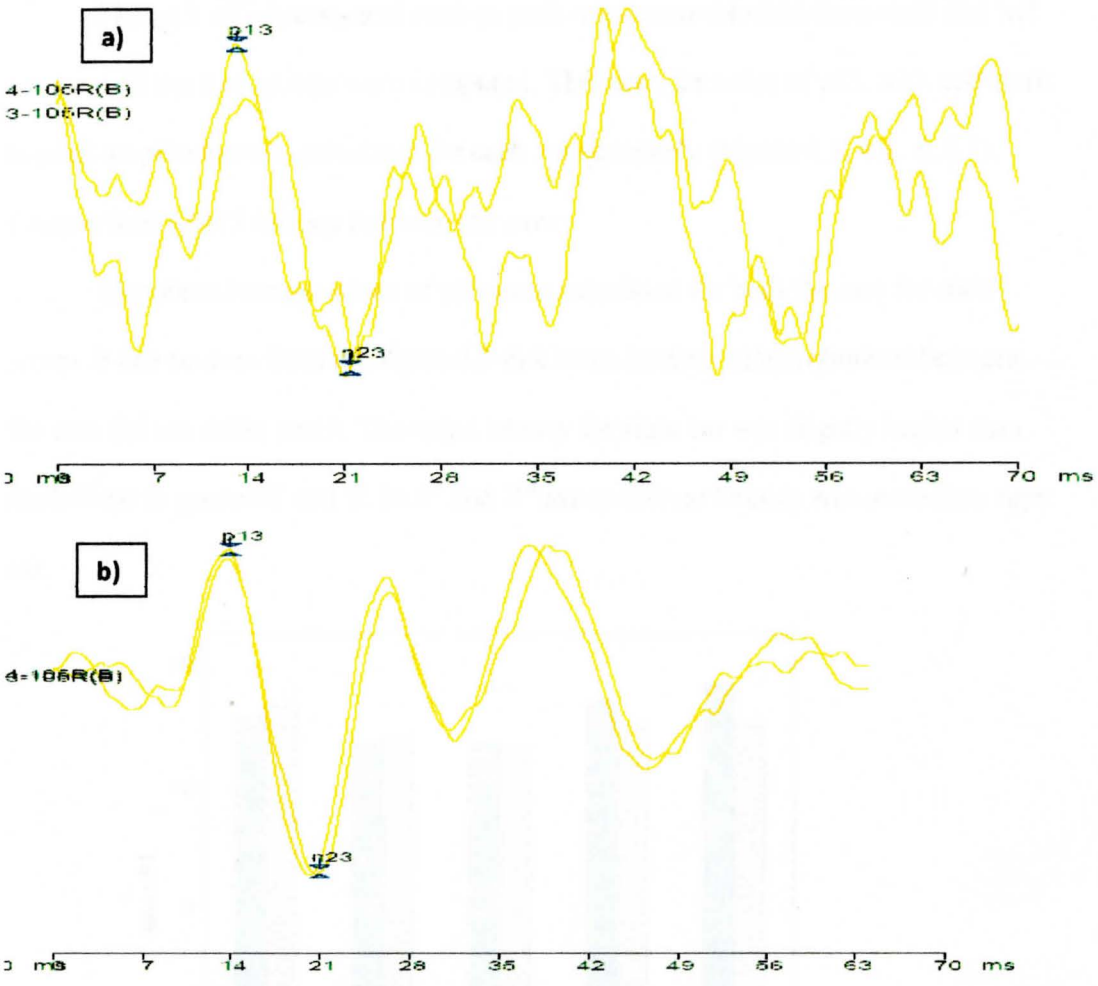

Figure 4.2: VEMP response showing p13 and n23 peaks recorded for 500 Hz tone burst presented at 105 dBnHL from two different individuals from group IV.

VEMP responses recorded in Group V

The VEMP was present in 13 out of 14 ears (92.85%) at 105 dBnHL. 5 out of 13 ears (39 %) showed noisy VEMP responses with poor wave morphology.

Comparison of VEMP parameters between the ears

The p13, n23 latency and peak to peak amplitude obtained from right and left ear from all the five groups were compared. The mean latencies of p13, n23, and peak to peak amplitude were calculated for each ear separately (Figure 4.3, 4.4, & 4.5).

Comparison of p13 latency between the ears

The mean latency values of p13 were calculated for both the ears for each group. It can be seen from the figure 4.3 that mean latency values obtained between the ears did not differ much. The mean latency for right ear was slightly higher than the left ear in group IV and V. In 1st and 2nd group left ear latency was more than right ear.

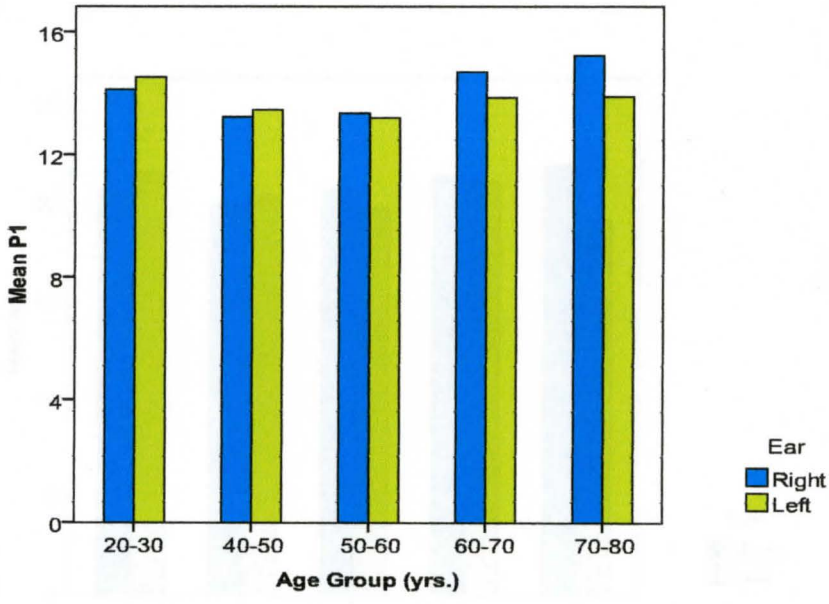

Figure 4.3: Mean latency value of p13 wave obtained in right and left ear across the groups.

To see the significant difference in p13 latency between the ears mixed ANOVA was done. It was noted that there was no significant difference in p13

latency between the ears [F (1, 59) = 0.205, p > 0.05]. No significant interaction between groups and ears [F (3, 59) = 1.301, p > 0.05]. To see the significant difference in p13 latency between the ears for group V, Wilcoxon's signed rank test was done. The results did not show any significant difference between the ears for p13 latency (/z/=0.365, p >0.05).

Comparison of n23 latency between the ears

The mean latency values of n23 were calculated for all the groups. Figure 4.4 shows the mean latency values obtained for right and left ears did not differ much. In group V, right ear n23 latency was larger than left ear. From 5th decade onwards right ear latency is slightly more than the left ear but in 1st and 2nd group it shows left side advantage.

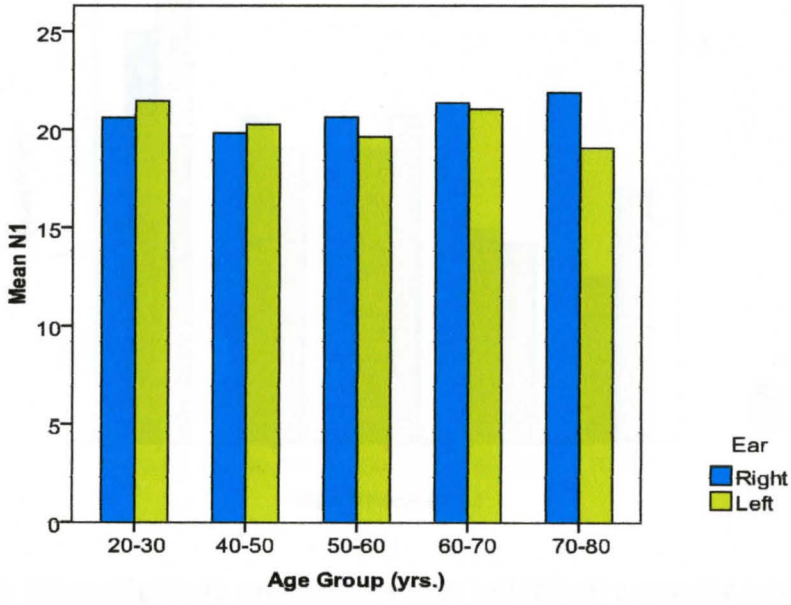

Figure 4.4: Mean of n23 latency obtained in right and left ear across the groups.

Mixed ANOVA was done to observe significant interaction of n23 latency across and within the group between the right and left ear. The results showed that

there was no significant difference in n23 latency between right and left ear [F (1, 59) = 0.499, p > 0.05] and interaction between group and ear was not significant [F (3, 59) = 1.003, p > 0.05]. No significant difference seen in n23 latency between the ears for group V in Wilcoxon's signed rank test (/z/=1.363, p >0.05).

Comparison of peak to peak amplitude (PPA) between the ears

The mean peak to peak amplitude values obtained for right and left ear across the groups are shown in figure 4.5. The mean amplitude of right ear was less than left ear for 1st and 3rd group. In other groups not much difference was seen between the two ears for amplitude. Mixed ANOVA was administered to see the significant difference between the ears and also across the groups.

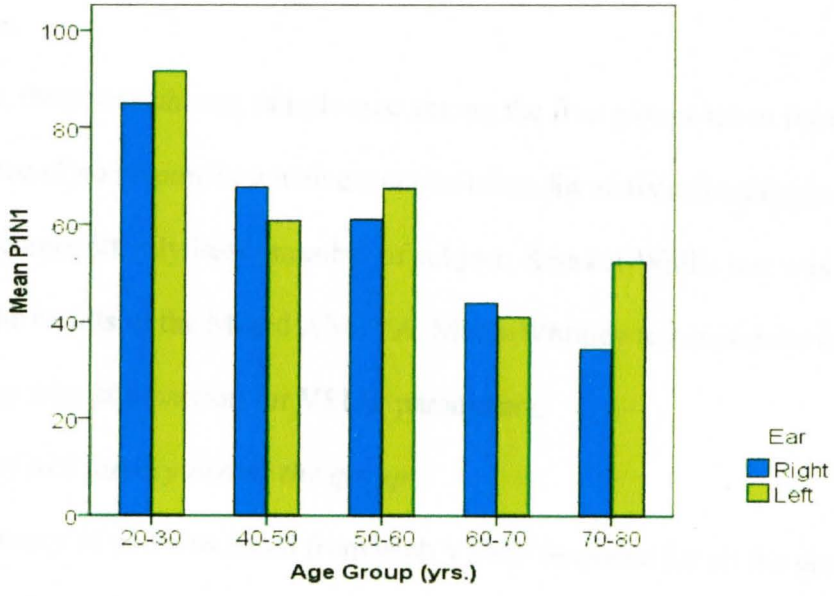

Figure 4.5: Mean of p13n23 amplitude for right and left ear across the groups.

There was no significant interaction for amplitude between group and ear [F (3, 59) = 0.849, p > 0.05]. No significant difference was obtained between the ears [F (1, 59) = 0.395, p > 0.05] for PPA. To see the significant difference in PPA amplitude

between the ears for group V, Wilcoxon's signed rank test was done and no significant difference between the ears was obtained (/z/=1.572, p >0.05).

Comparison of VEMP responses between the groups

A group comparison was made by comparing the latencies of p13 and n23 peaks and the peak to peak amplitude responses recorded from the five groups. Also the mean and standard deviation for the individual parameters were calculated using descriptive statistics. For the further statistical analysis the VEMP responses obtained from right and left ear were combined for all the groups as statistical analysis failed to show any significant difference in latency or amplitude values between the ears for all the groups.

Since, there was uneven sample size among the five groups taken for the study due to presence of no responses which cannot be taken for statistical analysis and group V had comparatively lesser number of subject; Kruskal-Wallis test was done to cross check the results of the Mixed ANOVA. Mann-Whitney test was done to compare group wise comparison for VEMP parameters.

Comparison of p13 latency across the group

The latency of p13 was noted from each VEMP response for all the groups. The mean and standard deviations for p13 latency for each group was calculated. The details of the mean value and standard deviation are shown in table 4.1.

Table 4.1: *Number of ears, mean and SD of p13 latency for each group*

Group	p13 latency		
	N	Mean	Std. Deviation
Group I (20-30)	62	14.32	1.69
Group II(40-50)	26	13.37	0.66
Group III (50-60)	20	13.29	1.04
Group IV (60-70)	24	14.24	1.79
Group V (70-80)	13	14.62	2.95

N- Number of ears in which VEMP was present

It can be viewed in the table that the shortest p13 latency was obtained from group III and largest latency obtained in group V. A slight increase in latency shift was noticed in age above 60 years.

To see whether the shift in latency reaches the significance level or not Mixed ANOVA was done. The result showed no significant difference [$F(3, 59) = 2.608$, $p > 0.05$] across group I to IV for p13 latency, but Kruskal-Wallis test reveals significant difference across five groups [chi-square=11.410, (Df =4), $p<0.05$]. The Mann-Whitney U test was done for group-wise comparison for p13 latency as Kruskal-Wallis test shows significant difference across the 5 groups. The outcome of the Mann-Whitney U test result is represented in table 4.2.

Table 4.2: *Significant level along with Z-value for p13 latency between the groups*

Fixed group	Dependent group	p13 latency	
		/Z/-value	Significant Level
Group I (20-30)	Group II(40-50)	2.397	**0.017**
	Group III (50-60)	2.455	**0.014**
	Group IV (60-70)	0.014	0.988
	Group V (70-80)	0.182	0.855
Group II(40-50)	Group III (50-60)	0.490	0.624
	Group IV (60-70)	2.200	**0.028**
	Group V (70-80)	1.917	0.055
Group III (50-60)	Group IV (60-70)	2.018	**0.044**
	Group V (70-80)	1.495	0.135
Group IV (60-70)	Group V (70-80)	0.255	0.799

It can be observed in the table 4.2 that the group I p13 latency differ significantly from group II and group III p13 latency. Group II and group III p13 latency was also significantly differed from group IV p13 latency. Whereas group V p13 latency did not differ significantly from the p13 latency obtained in any group.

Comparison of n23 latency across the group

The mean and standard deviations for n23 latency was obtained for each group. The details of the calculated mean value and standard deviation are shown in table 4.3.

Table 4.3: *Number of ears, mean and SD of n23 latency obtained in each group*

Group	n23 latency		
	N	Mean	Std. Deviation
Group I (20-30)	62	21.05	1.69
Group II(40-50)	26	20.07	2.23
Group III (50-60)	20	20.15	1.76
Group IV (60-70)	24	21.20	2.41
Group V (70-80)	13	20.59	3.48

N- Number of ears in which VEMP was present

The largest n23 latency was observed in group IV as can be seen in above table. Shortest latency was obtained in Group II. It has been observed that there is no specific pattern could be observed in n23 latency with age.

Mixed ANOVA result reveals that there was no significant difference [$F(3, 59) = 2.083$, $p > 0.05$] across first four groups for n23 latency. Kruskal-Wallis test was done to cross check Mixed ANOVA result and it shows that there was significant difference across the groups [chi-square=14.643, (Df =4), $p<0.05$]. The Mann-Whitney test was done to see the significant difference in latency values of n23 between the pair of groups. The outcome of the results of Mann-Whitney test is represented in table 4.4.

Table 4.4: *Z-value along with significant level for n23latency between the groups*

Fixed group	Dependent group	n23 latency	
		/Z/	Significant Level
Group I (20-30)	Group II(40-50)	3.196	**0.001**
	Group III (50-60)	2.255	**0.024**
	Group IV (60-70)	0.805	0.421
	Group V (70-80)	2.102	**0.036**
Group II(40-50)	Group III (50-60)	0.778	0.437
	Group IV (60-70)	2.256	**0.024**
	Group V (70-80)	0.255	0.799
Group III (50-60)	Group IV (60-70)	1.216	0.224
	Group V (70-80)	0.129	0.897
Group IV (60-70)	Group V (70-80)	1.307	0.191

It can be noted from the table 4.4 that n23 latency of group I differed significantly from rest of the groups except group IV n23 latency. Group II n23 latency differs significantly from group IV latency. Group III n23 latency did not differ significantly from group IV and V. No significant difference observed in n23 latency between group IV and V.

Comparison of peak to peak amplitude (PPA) across the group

Peak to peak amplitude was noted for each individual for all the groups. The mean and standard deviations for each group was calculated for PPA. The details of the mean value and standard deviation are shown in table 4.5.

Table 4.5: *Number of ears, mean and SD of peak to peak amplitude obtained in each group*

Group	peak to peak amplitude		
	N	Mean	Std. Deviation
Group I (20-30)	62	88.34	35.37
Group II(40-50)	26	64.28	34.58
Group III (50-60)	20	64.33	47.07
Group IV (60-70)	24	42.44	31.29
Group V (70-80)	13	42.72	20.04

N - Number of ears in which VEMP was Present

It is evident from the table that the peak to peak amplitude reduced with the increase in age. The first group had mean amplitude more than rest of the groups which can be clearly seen in figure 4.6. The decrease in amplitude is noted from 40 years onwards as can be observed from table 4.5.

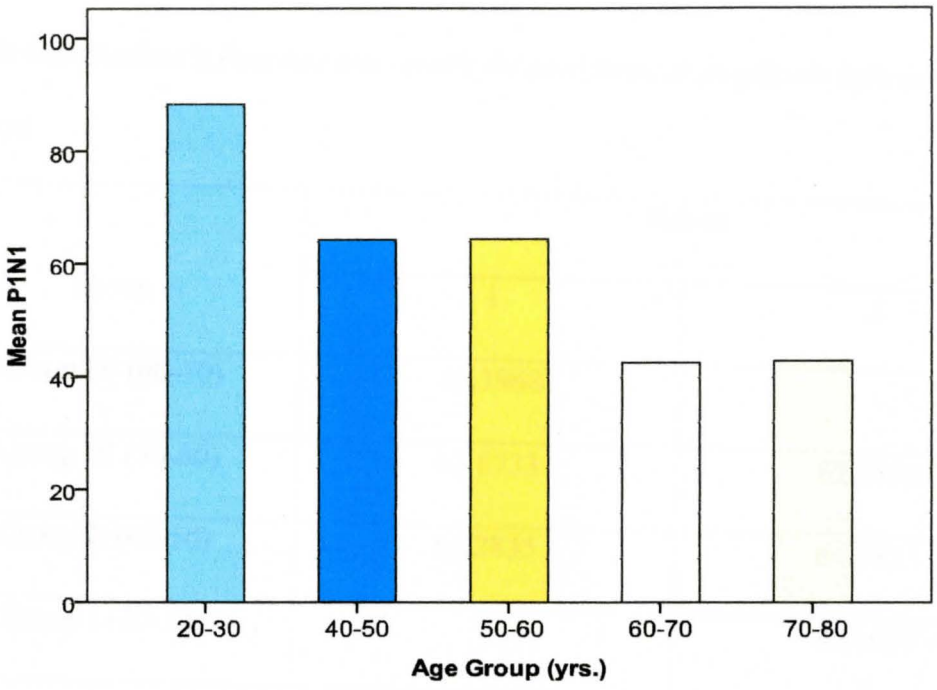

Figure 4.6: Showing Changes in peak to peak amplitude across different age groups.

As age increased amplitudes decreased. This reduction in amplitude is observed to be more in group IV and Vas seen in figure 4.6.

Mixed ANOVA was done to see significant difference in PPA for group I to IV. Since, the Mixed ANOVA showed significant differences across the groups [$F(3, 59) = 6.638$, $p < 0.05$] for PPA, Duncan's Post Hoc test was administered to know which two groups PPA differ significantly from each other. The results of Duncan's Post Hoc test are given in the table 4.6.

Table 4.6: *Duncan's Post hoc test results for peak to peak amplitude between the groups*

Group	Subset	
	1	2
Group IV (60-70)	42.3968	
Group III (50-60)	62.8733	62.8733
Group II (40-50)	64.2835	64.2835
Group I (20-30)		89.1057

There was no significant difference in peak to peak amplitude between group II and III. However, it can be observed from the table 4.6 that the individuals in group I had significantly more amplitude than group IV. To cross check the result of Mixed ANOVA, Kruskal-Wallis test was done. Kruskal-Wallis test results also showed significant difference across the groups for PPA [chi-square=36.036, (Df =4), $p<0.05$]. Hence, Mann-Whitney test was done to see which two groups differs significantly in PPA. Outcome of the Mann-Whitney test are shown in table 4.7.

Table 4.7: *Z-value along with significant level for peak to peak amplitude between the groups*

Fixed group	Dependent group	peak to peak amplitude	
		/Z/	Significant Level
Group I (20-30)	Group II(40-50)	2.808	**0.005**
	Group III (50-60)	2.473	**0.013**
	Group IV (60-70)	5.016	**0.000**
	Group V (70-80)	4.115	**0.000**
Group II(40-50)	Group III (50-60)	0.355	0.723
	Group IV (60-70)	2.524	**0.012**
	Group V (70-80)	1.847	0.065
Group III (50-60)	Group IV (60-70)	1.603	0.109
	Group V (70-80)	0.737	0.461
Group IV (60-70)	Group V (70-80)	0.732	0.464

From the table 4.7, it can be seen that there was significant difference in PPA between group 1 and rest of the groups. Group 2 differ significantly from group 4 in PPA. No other two groups differ significantly from each other.

Thus, it can be concluded from the results that the:

- VEMP results failed to show any significant latency and amplitude difference between the ears.

- The mean latency of p13 increased with age from 50 years onwards however, a statically significant difference was obtained from 60 years of age.
- There was no uniform trend in n23 latency with increase in age is observed.
- Peak to peak amplitude decreased with increase in age.
- Peak to peak amplitude was more for control group (20-30 years) and was least for individuals in Group IV (60-70 years) and V (70-80 years).
- The significant change in amplitude was noticed from 6^{th} decade of life.

Chapter 5

Discussion

The result obtained from different statistical analysis for each group and across the group for the p13 latency, n23 latency and peak-to-peak amplitude of VEMP responses are discussed below.

VEMP responses across the groups

Response rate

The percentage of occurrence of VEMP in Group I to V was about 96.88 %, 92.85%, 83.33 %, 85.71%, and 92.85% respectively. The response rate was above 90% in group I and II but tends to decrease in group III and IV. But, it increases to 92.85% in group V. A decrease in response rate was observed from 50 years onwards, however a significant decrement was observed in group IV i.e. above 60 years. Janky and Shepard (2009) reported that for the stimulus of 500Hz the response rate were between 95 to 100% for age from 20 years to 60 years but, it falls to 90% with age from 60 years onwards. Su et al. (2004) found that the response rate was above 90% up to age 60 years. But, above 60 years the response rate falls to 60%. Though in the current study group V had 92.85% occurrence of response, approximately 39% of them had degraded wave morphology. The sudden increase in response rate of group V that is 70-80 years can be accounted for the small sample size and also uneven populations across the group.

Ear wise comparison of VEMP parameters

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. Bickford, Jacobson, and Cody (1964) and Townsend and Cody (1971), observed symmetric

responses from both sides which is in accordance with the result of the current study. Robertson and Ireland (1995) obtained symmetric responses from SCM muscles to clicks presented unilaterally to 7 normal participants. No significant difference in any VEMP parameters between the right and left sides was also reported by Lee et al. (2008). Vivekanandh (2009) also reported that the latency of p13 and n23 and the peak to peak amplitude between right and left ear did not differ significantly.

Comparison of VEMP responses between the groups

When VEMP parameters were compared across the groups it was found that there was a difference in the p13 and n23 latency across the group. However a significant reduction in the peak to peak amplitude was observed across the groups.

Latency

In this study we did not find a uniform relationship between p13 and n23 latency with age. There is little agreement regarding the effect of age on P13 and n23 latencies. Janky and Shepard (2009) did not find a uniform relationship between p13 and n23 latencies and age. Basta et al. (2005) report no difference in either latency measurement across age groups. In-contrary an increase in both P13 and n23 latencies has been reported with age (Brantberg et al., 2007; Lee et al., 2008; Zapala & Brey, 2004).

p13 latency

This study suggests significantly longer P13 latencies with younger age i.e. group I had longer p13 latency than group II and III. Janky and Shepard (2009) also observed significantly longer p13 latencies with younger age. Conversely, group II and III has shorter p13 latency than group IV. So there is no uniform correlation is seen between p13 latency and age which is in accordance with previous findings. Su

et al. (2004) reported that the p13 latency had a trend to prolong as age increased, but no significant correlation existed between them. The p13 latency did not significantly correlated with age was also reported by Welgampola and Colebatch (2001b).

n23 latency

Latency of n23 was significantly longer in control group than older age groups except group IV. Group II n23 latency is smaller than group IV. So no clear relationship was observed between n23 latency and increase in age. Su et al. (2004) observed prolongation in n23 latency as age increased. Welgampola and Colebatch (2001b) also report a weak correlation for n23 latency and age.

Peak to Peak Amplitude (PPA)

The present study showed that there was a significant decrease in peak to peak amplitude with age. The control group had amplitude significantly greater than rest of the groups. Reductions in VEMP amplitude with increased age has been a consistent finding across investigations (Basta et al., 2005, 2006; Brantberg et al., 2007; Lee et al., 2008; Ochi & Ohashi, 2003; Su et al., 2004; Welgampola & Colebatch, 2001b; Zapala & Brey, 2004). The age related changes documented in the VEMP response may be attributed to the subsequent decline in overall neuroanatomy and physiological function. Studies indicate that with an increase in age, a decrease in number of otoconia, specifically within the saccule and also a decreased in number of neurons within the medial vestibular nucleus observed (Ross, Peaco, Johnsson, & Allard, 1976; Tang, Lopez, & Baloh, 2002). A decrease in the number of cell bodies in Scarpa's ganglion (Richter, 1980) and a loss of neurons in the vestibular nuclear complex (Lopez et al., 1997) with age have also been reported. Thus, the loss of cells or neurons at different level would have resulted in reduction in amplitude with age.

In this study decrease in amplitude was noted from 40 year onwards. It was observed that there was a significant difference in peak to peak amplitude between group I and rest of the groups. The decrease in amplitude for both air and bone conducted VEMP was observed from 40 years and above (Basta et al., 2005, 2006). VEMP amplitude seemed to decrease less with age among those, younger than 30 years (Brantberg et al., 2007). The vestibular epithelium shows hair cell loss of 6% per decade between the ages of 40 and 90 years (Rosenhall, 1973). Richter (1980) reported a decrease in hair cell density from the age of 30 onwards with similar degrees of degeneration in all vestibular end organs. Bergstrom (1973) reported a decrease in the number of vestibular nerve fibres by 5.5% per decade between the ages of 40 and 90 years. Johnsson and Hawkins (1972) reported a loss of otoconia from the age of 30 onwards, affecting the saccule more severely than the utricle. A decrease in the number of thick myelinated primary vestibular afferents from the age of 40 with a 37% reduction in fibre counts in subjects aged 70–85 years has also been described (Bergstrom, 1973). The vestibular nuclear complex shows an age related neuronal loss of 3% per decade from the age of 40, affecting all 4 nuclei (Lopez et al., 1997). Most of the studies suggested that loss of cells or neural degeneration due to age starts at the age of 40 years. These changes in vestibular system with age might have taken place in subjects, who have participated in this study and thus resulted in significant reduction in amplitude from 40 years onwards.

The most significant change in peak to peak amplitude was noted in subjects age over 60 years. The mean amplitude of p13-n23 was significantly less in group IV and V. Welgampola and Colebatch (2001b) noted a similar reductions in click evoked VEMP amplitude in the 6th decade with reductions in galvanic VEMP in the 7th

decade and propose degeneration of the peripheral system prior to degeneration of the neural supply. Basta et al. (2005, 2006) obtained greatest reduction in VEMP amplitude for both air and bone conducted stimuli from 60 years onwards. When VEMP amplitude was compared across groups at similar EMG levels (i.e., 30 and 50 μV) the older group exhibited significantly smaller amplitudes than the younger group. These findings suggest that the decrement in VEMP amplitude observed in subjects over the age of 60 are due to the degenerative effects of aging on the vestibular system rather than SCM muscle tonus (Tampas et al., 2006). Jhanky and Shepard (2009) also found reduced response rate and flattened frequency tuning curve for individuals over the age of 60 years. Su et al. (2004) reports that as age increased over 60 years, the VEMP response rate and amplitude decreased dramatically. Thus, the results of the current study suggest that significant changes in VEMP amplitude could be observed at age above 60 years. This also suggests that a significant degeneration of anatomical structures of the vestibular system is likely to take place age above 60 years, which in turn would result in significant reduction in amplitude.

Chapter 6

Summary and Conclusion

Vestibular evoked myogenic potential (VEMP) is an electromyographic response to loud auditory stimuli that is recorded at the sternocleidomastoid muscle during tonic contraction. The VEMP responses were first reported by Geisler, Frishkopf, and Rosenblith (1958) and identified by Bickford et al. (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 & Cox, 2004). The VEMP waveform consists of an early positive-negative component that occurs at 13 ms to 23 ms (p13-n23 or P1-N1) and a later negative-positive component that occurs at 34 ms to 44 ms (n34-p44 or N3-P4) (Colebatch & Halmagyi, 1992).

Su et al. (2004) showed that as age increased over 60 years, the VEMP response rate decreased dramatically. The VEMP amplitude decreased significantly with age in comparison to increase in n23 latency. Lee et al. (2008) observed that VEMP amplitude decreased with increasing age, which may be caused by a decrease in cervical muscle tonicity with aging and both p13 and n23 latencies were prolonged with age.

Age-related morphological changes affecting the vestibular system from the end organs to the central nuclei are well documented. The vestibular epithelium shows hair cell loss of 6% per decade between the ages of 40 and 90 years (Rosenhall, 1973). Bergstrom (1973) reported a decrease in the number of vestibular nerve fibres by 5.5% per decade over a similar age range. Richter (1980) reported a decrease in hair cell density from the age of 30 onwards with similar degrees of degeneration in

all vestibular end organs. Thus, age-related degeneration affects the pathways mediating vestibular reflexes at multiple levels. It is thus essential to have database for VEMP responses in elderly to differentiate pathological condition from normal degeneration processes. The VEMP has been taken as a reliable clinical tool in the present study which was aimed to:

- Observe age related changes in VEMP results and establish database for VEMP responses in elderly population.
- Know the age at which a significant change can occur, and
- Check for the ear wise differences in VEMP responses across the groups.

A total of 79 (145 ears) subjects participated in the study. They were divided into five groups. Group I: Consisted of 62 ears of 32 individuals. These individuals were between the age ranging from 20 to 30 years with normal hearing sensitivity without vestibular symptoms, served as the control; Group II: Consisted of 14 individuals. VEMP was recorded from 26 ears and the individuals were between the age ranging from 40 to 50 years; Group III: In this group response was obtained from 20 ears of 12 individuals with age range between 50 to 60 years; Group IV: 14 individual were taken for the study and response could be recorded from 24 ears. The participants age varied from 60 to 70 years; Group V: Individuals in the age range of 70 to 80 years were included for the study. VEMP responses were present in 13 ears of 7 individuals.

In the present study participants of sensory-neural hearing loss of any degree (up to profound) were taken in group II, III, IV and V as Bickford et al. (1964); Colebatch et al. (1994); Rosengren and Colebatch (2006); Takegoshi and Murofushi

(2003); Wu and Young (2002) reported that VEMP potential is independent of degree of sensory neural hearing loss.

Audiological evaluation involving pure tone audiometry, uncomfortable level, tympanometry and reflexometry, and auditory brainstem response were done to select the participants. Auditory brainstem response (ABR) was recorded for all the groups to rule out presence of retro-cochlear pathology. The ipsilateral VEMP responses were recorded from both the ears using 500 Hz tone burst presented at 105 dB nHL for all the individuals. 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. The p13 latency, n23 latency and peak to peak amplitude and also the ear wise comparisons across the groups were analyzed using statistical package for social sciences (SPSS) software, version 16.

The following statistical analyses were carried out within and across the groups of subjects:

- Descriptive statistics was done to obtain the mean and standard deviation for all the parameters of VEMP for all the groups.
- For group I to IV, Mixed analysis of variance (Mixed ANOVA) was done to check for significant differences in the VEMP parameters between the ears and across the group.
- Duncan's Post Hoc test was administered to see significant difference in VEMP parameters between the groups, in case mixed ANOVA showed significant interaction.

- To see ear-wise difference in the VEMP parameters for individuals in group V, Wilcoxon's signed ranks test was administered as the sample size was small.
- Kruskal-Wallis test was done to cross check Mixed ANOVA test results, since the sample size was uneven across the groups (including group V).
- Mann-Whitney U test was done to check for significant differences in the VEMP parameters between any two groups, wherever Kruskal-Wallis test showed significant difference.

The results of the statistical analysis revealed the following:

- The percentage of occurrence of VEMP in Group I to V was about 96.88 %, 92.85%, 83.33 %, 85.71%, and 92.85% respectively. The VEMP response rate decreases from 50 years onwards and similar observation was seen in group IV i.e. above 60 years.

Table 6.1: *Mean and SD of p13, n23 latency and P13n23 amplitude across the group*

Group	p13 latency		n23 latency		p13 n23 amplitude	
	Mean	SD	Mean	SD	Mean	SD
Group I	14.32	1.69	21.05	1.69	88.34	35.37
Group II	13.37	0.66	20.07	2.23	64.28	34.58
Group III	13.29	1.04	20.15	1.76	64.33	47.07
Group IV	14.24	1.79	21.20	2.41	42.44	31.29
Group V	14.62	2.95	20.59	3.48	42.72	20.04

- The ear wise comparison within and across the groups revealed that there was no significant difference in VEMP parameters recorded from right and left ear for all the groups.
- Comparison of VEMP parameters across the groups revealed a significant difference in the p13 and n23 latency and also the peak to peak amplitude. There is no uniform trend seen for n23 latency with increase in age. The mean latency of p13 increases with age above 50 years onwards however a statically significant difference was observed for group IV (60-70 years) only.
- As age increased amplitude was decreased. The control group had amplitude significantly greater than rest of the groups. In this study decrease in amplitude was noted from 40 year onwards. The most significant change in peak to peak amplitude was noted after 60 years.

The age related changes documented in the VEMP response may be attributed to the subsequent decline in overall neuroanatomy and physiological function. Several studies indicated that with an increase in age a decrease in the number of otoconia, specifically within the saccule as well as a decreased number of neurons within the medial vestibular nucleus occurs (Ross et al., 1976; Tang et al., 2002).

Conclusion

The present study aimed to observe age related changes in VEMP results. The data shown in the table 6.1 could be used as norms for elderly people. One can suspect a significant variation in amplitude but not necessary to observe increase in latency for p13 and n23 with age. A significant change and poor morphology of VEMP can be anticipated age above 60 years.

Implications of the study

- The result of the current study gives the database for VEMP responses for elderly Indian population in.
- The latency and the amplitude data can be used as normative for future research and clinical evaluation.
- The result suggests that the comparison of VEMP parameters between right and left ear is not essential.
- This study gives a baseline to compare the subjects with vestibular disorder to normals for elderly population.
- 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 older individuals in Indian population to see the age related change.
- VEMP responses from gender matched individuals can be compared with age.
- The comparison across the age can be done with larger and even sample size.

References

Akin, F. W., & Murnane, O. D. (2008). Vestibular evoked myogenic potential. In G. P. Jacobson & N. T. Shepard (Ed.), *Balance function assessment and management.* (2 ed., pp. 403-434). Brisbane: Plural Publishing Inc.

Akin, F. W., Murnane, O. D., & Proffitt, T. M. (2003). The effects of click and tone-burst stimulus parameters on the vestibular evoked myogenic potential (VEMP). *Journal of the American Academy of Audiology,* 14, 500–509.

Akin, F. W., Murnane, O. D., Panus, P. C., Caruthers, S. K., Wilkinson, A. E., & Proffitt, T. M. (2004). The influence of voluntary tonic EMG level on the vestibular-evoked myogenic potential. *Journal of Rehabiltaion Research and Development,* 41, 473-80.

Alpini, D., Pugnetti, L., Caputo, D., Cornedio, A., Capobianco, S., & Cesarani, A. (2004). Vestibular evoked myogenic potentials in multiple sclerosis: Clinical and imaging correlations. *Multiple Sclerosis*, 10, 316-321.

American National Standards Institute (1991). *Maximum permissible ambient noise levels for audiometric test rooms (ANSI S3.1-1991).* New York: Acoustical Society of America.

Basta, D., Todt, I., & Ernst, A. (2006). Characterization of age-related changes in vestibular evoked Myogenic potentials. *Journal of Vestibular Research,* 17, 93–98.

Basta, D., Todt. I., & Ernst, A. (2005). Normative data for P1/N1-latencies of vestibular evoked myogenic potentials induced by air- or bone-conducted tone bursts, *Clinical Neurophysiology,* 116, 2216–2219.

Bergstrom, B. (1973). Morphology of the vestibular nerve; the number of myelinated vestibular nerve fibers at various ages. *Acta Otolaryngology,* 76, 173-179.

Bickford, R. G., Jacobson, J. L., & Cody, D. T. (1964). Nature of average evoked potentials to sound and other stimuli. *Annals of New York Academy of Sciences,* 112, 204–223.

Boleas-Aguirre, M., Sánchez-Ferrándiz, N., Artieda, J., & Pérez, N. (2007). Vestibular evoked myogenic potentials and benign paroxysmal positional vertigo. *Acta Otorrinolaringology*, 58, 173-177.

Brantberg, K., & Fransson, P. A. (2001). Symmetry measures of vestibular evoked myogenic potentials using objective detection criteria. *Scandavian Audiology*, 30, 189-196.

Brantberg, K., Bergenius, J., & Tribukait, A. (1999). Vestibular- evoked myogenic potentials in patients with dehiscence of the superior semicircular canal. *Acta Otolaryngologica*, 119, 633–640.

Brantberg, K., Granath, K., & Schart, N. (2007). Age-related changes in vestibular evoked myogenic potentials. *Audiology and Neuro-Otology,*12, 247-253.

Bronstein, A. M., Faldon, M., Rothwell, J., Gresty, M. A., Colebatch, J., & Ludman, H. (1995). Clinical and electrophysiological findings in the Tullio phenomenon. *Acta Otolaryngologica (Stockholm) Supplement*, 520, 209-211.

Carhart, R., & Jerger, J. F. (1959). Preferred method for clinical determination of pure-tone thresholds. *Journal of Speech and Hearing Disorders*, 24, 330-345.

Cazals, Y., Aran, J. M., Erre, J. P., Guilhaume, A., & Aurousseau, C. (1983). Vestibular acoustic reception in the guinea pig: A saccular function? *Acta Otolaryngologica,* 95, 211–217.

Chen, C. H., & Young, Y. H. (2003). Vestibular evoked myogenic potentials in brainstem stroke. *Laryngoscope*, 113, 990–993.

Chen, C. N., Wang, S. J., Wang, C. T., Hsieh, W. S., & Young, Y. H. (2007). Vestibular evoked myogenic potentials in newborns. *Audiology and Neuro-Otology,* 12, 59-63.

Chen, C. W., Young, Y. H., & Wu, C. H. (2000). Vestibular neuritis: Three-dimensional videonystagmography and vestibular evoked myogenic potential results. *Acta Otolaryngologica*, 120, 845–848.

Cheng, P. W., & Murofushi, T. (2001a). The effect of rise/fall time on vestibular-evoked myogenic potential triggered by short tone bursts. *Acta Otolaryngologica,* 121, 696–699.

Cheng, P. W., & Murofushi, T. (2001b). The effects of plateau time on vestibular-evoked myogenic potentials triggered by tone bursts. *Acta Otolaryngologica,* 121, 935–938.

Chihara, Y., Ito, K., Sugasawa, K., & Shin, M. (2007). Neurological complications after acoustic neurinoma radiosurgery: revised risk factors based on long-term follow-up. *Acta Otolaryngology Supplement,* 55, 65-70.

Christiana, K., Bhat, J., & Kumar, K. (2008). Vestibular evoked myogenic potential in subjects with noise induced hearing loss. Paper presentation at *ISHACON-40.*

Cody, D. T. R., & Bickford, R. G. (1969). Average evoked myogenic responses in normal man. *Laryngoscope,* 79, 400–446.

Colebatch, J. G., & Halmagyi, G. M. (1992). Vestibular evoked potentials in human neck muscles before and after unilateral vestibular deafferentation. *Neurology,* 42, 1635–1636.

Colebatch, J. G., Day, B. L., Bronstein, A. M., Davies, R. A., Gresty, M. A., & Luxon, L. M. (1998). Vestibular hypersensitivity to clicks is characteristic of the Tullio Phenomenon. *Journal of Neurology, Neurosurgery, and Psychiatry,* 65, 670-678.

Colebatch, J. G., Halmagyi, G. M., & Skuse, N. F. (1994). Myogenic potentials generated by a click-evoked vestibulocolic reflex. *Journal of Neurology, Neurosurgery, and Psychiatry,* 57, 190–197.

Colledge, N. R., Wilson, J. A., Macintyre, C. C., & MacLennan, W. J. (1994). The prevalence and characteristics of dizziness in an elderly community. *Age Ageing*, 23, 117-120

Davis, L. E. (1994) Dizziness in elderly men. *Journal of American Geriatric Society*, 42, 1184–1188.

De Vries, H., & Bleeker, J. D. (1949). The microphonic activity of the labyrinth of the pigeon: The response of the cristae in the semicircular canals. *Acta Otolaryngologica, 37, 298-306.*

Didier, A., & Cazals, Y. (1989). Acoustic responses recorded from the saccular bundle on the eighth nerve of the guinea pig. *Hearing Research*, 37, 123–128.

Fay, R. R., & Popper, A. N. (1980). Structure and function in teleost auditory system. In A. N. Poper & R. R. Fay (Eds.), *Comparative studies of hearing in vertebrates* (pp. 4–43). New York: Springer Verlag.

Ferber-Viart, C., Dubreuil, C., & Duclaux, R. (1999). Vestibular evoked myogenic potentials in humans: A review. *Acta Otolaryngologica,* 119, 6–15.

Ferber-Viart, C., Dubreuil, C., Duclaux, R,. & Collet, L. (1995). Re´flexe sonomoteur vestibulaire dans les neurinomes de l'acoustique. *Rev Laryngol Otol Rhinol,* 116, 47–51.

Ferber-Viart, C., Duclaux, R., Colleaux, B., & Dubreuil, C. (1997). Myogenic vestibular-evoked potentials in normal subjects: A comparison between responses obtained from sternomastoid and trapezius muscles. *Acta Otolaryngologica,* 117, 472–481.

Fife, T. D., Tusa, R. J., Furman, J. M., Zee, D. S., Frohman, E., Baloh, R. W., Hain, T., Goebel, J., Demer, J., & Eviatar, L. (2000). Assessment: vestibular testing techniques in adults and children. *Neurology,* 55, 1431-1441.

Geisler, C. D., Frishkopf, L. S, & Rosenblith, W. A. (1958). Extra cranial responses to acoustic clicks in man. *Science,* 128, 1210–1211.

Halmagyi, G. M., & Colebatch, J. G. (1995). Vestibular evoked myogenic potentials in the sternomastoid muscle are not of lateral canal origin. *Acta Otolaryngologica Supplement. 520,* 1–3.

Halmagyi, G. M., & Curthoys, I. S. (1999). Clinical testing of otolith function. *Annals of the New York Academy of Sciences,* 871, 195–204.

Halmagyi, G. M., & Curthoys, I. S. (2000). *Otolith Function Tests in Vestibular Rehabilitation* (2nd edition; pp.195-214), Herdman SJ (ed), F.A. Davis Co., Philadelphia.

Halmagyi, G. M., Colebatch, J. G., & Curthoys, I. S. (1994). New tests of vestibular function. *Baillieres Clinical Neurology*, 3, 485-500.

Halmagyi, G. M., Yavor, R. A., & Colebatch, J. G. (1995). Tapping the head activates the vestibular system: A new use for the clinic reflex hammer. *Neurology,* 45, 1927–1929.

Hong, S. M., Yeo, S. G., Kim, S. W., & Cha, C. I. (2008). The results of vestibular evoked myogenic potentials, with consideration of age-related changes, in vestibular neuritis, benign paroxysmal positional vertigo, and Meniere's disease. *Acta Otolaryngologica*, 128, 861-865.

Huang, T. W., Su, H. C., & Cheng, P. W. (2005). Effect of click duration on vestibular-evoked myogenic potentials. *Acta Otolaryngol*, 125, 141–144.

Ito, K., Ishimoto, S. I., & Murofushi. T. (2001). Narrow Internal Auditory Meatus: An Idiopathic Case Confirming the Origin and Pathway of Vestibular Evoked Myogenic Potentials in Humans. *Arch Otolaryngol Head Neck Surg*, 127, 275-278.

Itoh, A., Kim, Y. S., Yoshioka, K., Kanaya, M., Enomoto, H., & Hiraiwa, F. (2001). Clinical study of vestibular-evoked myogenic potentials and auditory brainstem responses in patients with brainstem lesions. *Acta Otolaryngologica (Supplement),* 545, 116–119.

Janky, K. L., & Shepard, N. (2009). Vestibular Evoked Myogenic Potential (VEMP) Testing: Normative Threshold Response Curves and Effects of Age. *Jounal of American Academy of Audiology*, 20, 515-522.

Johnsson, L. G., & Hawkins, J. E. (1972). Sensory and neural degeneration with ageing as seen in microdissection of the human inner ear. *Ann Otolaryngol Rhinol Laryngol,* 81, 179-193.

Jonsson, R., Sixt, E., Landah,l S., & Rosenhall, U. (2004). Prevalence of dizziness and vertigo in an urban elderly population. *Journal of Vestibular Research*, 14, 47-52.

Kelsch, T. A., Schaefer, L. A., & Esquivel, C. R. (2006). Vestibular evoked myogenic potentials in young children: Test parameters and normative data. *Laryngoscope,* 116, 895-900.

Kumar, K. (2006). Vestibular evoked myogenic potential in normals and in individual with dizziness. Unpublished Master's Dissertation. *University of Mysore, India.*

Kumar, K., Bharti, S. S., Sinha, N. S., Singh, A. B., & Barman, A. (2007). Vestibular Evoked Myogenic Potential as a tool to identify vestibular involvement in auditory neuropathy. *Asia Pacific Journal of Speech, Language, and Hearing,* 10, 181-187.

Kuo, S. W., Yang, T. H., & Young, Y. H. (2005). Changes in vestibular evoked myogenic potentials after Meniere's attacks. *Annals of Otology, Rhinology, and Laryngology,* 114, 717-721.

Lee, S. K., Cha, C. II, Jung, T. S., Park, D. C. & Yeo, S. E. (2008). Age-related differences in parameters of vestibular evoked myogenic potentials. *Acta Oto-Laryngologica*, 128, 66 -72.

Li, M. W., Houlden, D., & Tomlinson, R. D. (1999). Click evoked EMG responses in sternocleidomastoid muscles: Characteristics in normal subjects. *Journal of Vestibular Research,* 9, 327–334.

Lopez, I., Honrubia, V., & Baloh, R. W. (1997). Aging and the human vestibular nucleus. *Journal of Vestibular Research*, 7, 77-85.

Maes, B. L., Vinck, E., De Vel, W., D'haenens, A., Bockstael, H., Keppler, B., Philips, F. , Swinnen, I., & Dhooge. (2008). The vestibular evoked myogenic potential: A test–retest reliability study *Clinical Neurophysiology*, 120, 594-600.

Mansa, M. (2009). Vestibular evoked myogenic potential in individuals with Noised induced hearing loss. Unpublished Master's Dissertation. *University of Mysore, India.*

Matsuzaki, M., Murofushi, T., & Mizuno, M. (1999). Vestibular evoked myogenic potentials in acoustic tumor patients with normal auditory brainstem responses. *European Archives of Otorhinolaryngology,* 256, 1–4.

McCue, M. P., & Guinan, J. J., Jr. (1994). Acoustically responsive fibers in the vestibular nerve of the cat. *Journal of Neuroscience,* 14, 6058–6070.

McCue, M. P., & Guinan, J. J., Jr. (1995). Spontaneous activity and frequency selectivity of acoustically responsive vestibular afferents in cat. *Journal of Neurophysiology,* 72, 1563–1572.

McCue, M. P., & Guinan, J. J., Jr. (1997). Sound-evoked activity in primary afferent neurons of a mammalian vestibular system. *The American Journal of Otology,* 18, 335–360.

Merchant, S. N. (1999). A Method for quantitative assessment of vestibular otopathology. *Laryngoscope*, 109, 1560–1569.

Merchant, S. N., Velazquez-Villasenor, L., Tsuji, K., Glynn, Rj., Wall, C3rd., & Rauch, S. D. (2000). Temporal bone studies of the human peripheral vestibular system: normative vestibular hair cell data. *Ann Otol Rhinol Laryngol Suppl,* 181, 3-13

Minor, L. B. (2005). Clinical manifestation of superior semicircular canal dehiscence. *Laryngoscope*, 115, 1717-1727.

Murofushi, T., Matsuzaki, M., & Mizuno, M. (1998). Vestibular evoked myogenic potentials in patients with acoustic neuromas. *Archives of Otolaryngology-Head & Neck Surgery,* 124, 509–512.

Murofushi, T., Matsuzaki, M., & Mizuno, M. (1999). "Short tone burst-evoked myogenic potentials on the sternocleidomastoid muscle: are these potentials also of vestibular origin?" *Arch Otolaryngol Head Neck Surg,* 125, 660-664.

Murofushi, T., Ochiai, A., Ozeki, H., & Iwasaki, S. (2004). Laterality of vestibular evoked myogenic potentials. *International Journal of Audiology*, 43, 66–68.

Ochi K., Ohashi, T., & Kinoshita, H. (2002). Acoustic tensor tympani response and vestibular-evoked myogenic potential. *Laryngoscope*, 112, 2225-2229.

Ochi, K., & Ohashi, T. (2003). Age-related changes in the vestibular-evoked myogenic potentials. *Otolaryngology - Head and Neck Surgery*, 129, 655–659.

Ochi, K., Ohashi, T., & Nishino, H. (2001). Variance of vestibular evoked myogenic potentials. *Laryngoscope,* 111, 522–527.

Ochi, K., Ohashi. T., & Watanabe, S. (2003). Vestibular-evoked myogenic potential in patients with unilateral vestibular neuritis: abnormal VEMP and its recovery. *Journal of Laryngology and Otology,* 117, 104–108.

Ozeki, H., Iwasaki S., & Murofushi, T. (2005). Effect of stimulation repetition rate on galvanicevoked vestibulo-collic reflexes. *Acta Oto-Laryngologica*, 125, 159-162.

Park, S. H., Cha, C. I., Kim, K. H., Kim, H., Hwang, M. G., & Hong, N. P. (2001). The clinical significance of vestibular evoked Myogenic potential evoked by click sound. *Korean Journal of Otolarygol HeadNeck Surg*, 44, 1253-8.

Pollak, L., Kushnir, M., & Stryjer, R. (2006). Diagnostic value of vestibular evoked myogenic potentials in cerebellar and lower- brainstem strokes. *Neurophysiologic Clinique,* 36, 227-233.

Popper, A., Platt, C., & Saidal, W. (1982). Acoustic functions in the fish ear. *Trends in Neuroscience,* 5, 276–280.

Rauch, S. D., Merchant, S. N., & Thedinger, B. A. (1989). Meniere's syndrome and endolymphatic hydrops: Doubleblind temporal bone study. *Annals of Otology, Rhinology & Laryngology,* 98, 873–883.

Rauch, S. D., Zhou, G., Kujawa, S. G., Guinan, J. J., & Herrmann, B. S. (2004). Vestibular evoked myogenic potentials show altered tuning in patients with Meniere's disease. *Otology & Neurotology,* 25, 333–338.

Richter, E. (1980). Quantitative study of human Scarpa's ganglion and vestibular sensory epithelia. *Acta Otolaryngol,* 90, 199-208.

Robertson, D. D., & Ireland, D. J. (1995). Vestibular evoked myogenic potentials. *The Journal of Otolaryngology,* 24, 3–8.

Rosengren, S. M., & Colebatch, J. G. (2006). Vestibular evoked potentials (VEPs) in patients with severe to profound bilateral hearing loss. *Clinical Neurophysiology,* 117, 1145-53.

Rosenhall, U. (1973). Degenerative patterns in the aging human vestibular neuroepithelia. *Acta Otolaryngol*, 76, 208-220.

Ross, M. D., Peacor, D., Johnsson, L. G., & Allard, L. F. (1976). Observations on normal and degenerating human otoconia. *Ann Otol Rhinol Laryngol*, 85, 210–226.

Seo, T., Node, M., Yukimasa, A., & Sakagami, M. (2003). Furosemide loading vestibular evoked myogenic potentials for unilateral Meniere's disease. *Otology and Neurotology,* 24, 283-288.

Sheykholeslami, K., Megerian, C.A., Arnold, J. E., & Kaga, K. (2005). Vestibular-evoked myogenic potentials in infancy and early childhood. *Laryngoscope,* 115, 1440-1444.

Sheykholeslami, K., Murofushi, T., Kermany, M. H., & Kaga, K. (2000). Bone-conducted evoked myogenic potentials from the sternocleidomastoid muscle. *Acta Otolaryngologica*, 120, 731-734.

Sheykholeslami, K., Schmerber, S., Kermany, M. H., & Kaga, K. (2005). Sacculo-collic pathway dysfunction accompanying auditory neuropathy: Case report. *Acta Otolaryngologica*, 125, 786–791.

Shimizu, K., Murofushi, T., Sakurai, M., & Halmagyi, M. (2000). Vestibular evoked myogenic potentials in multiple sclerosis. *Journal of Neurology, Neurosurgery, and Psychiatry,* 69, 276–277.

Streubel, S. O., Cremer, P. D., Carey, J. P., Weg, N., & Minor, L. B. (2001). Vestibular-evoked myogenic potentials in the diagnosis of superior canal dehiscence syndrome. *Acta Otolaryngologica (Supplement),* 545, 41–49.

Su, H. C., Huang, T. W., Young, Y. H., & Cheng, P. W. (2004). Aging effect on vestibular evoked myogenic potential. *Otology & Neurotology*, 25, 977–980.

Takegoshi, H., & Murofushi, T. (2003). Effect of white noise on vestibular evoked myogenic potentials. *Hearing Research*, 176, 59-64.

Tampas, J. W., Akin, F. W., Murnane, O. D., & Clinard, C. (2006). The effects of aging on tonic EMG level and VEM*P*. Poster session presented at the annual meeting of the *American Academy of Audiology*, Minneapolis, MN.

Tang, Y., Lopez, I., & Baloh, R. (2002). Age-related change of the neuronal number in the human medial vestibular nucleus: a stereological investigation. *J Vestib Res*, 11, 357–363.

Todd, N. P., Cody, F. W. J., & Banks, J. R. (2000). A saccular origin of frequency tuning in myogenic vestibular evoked potentials? Implications for human responses to loud sounds. *Hearing Research,* 141, 180–188.

Townsend, G. L., & Cody, D. T. R. (1971). The averaged inion response evoked by acoustic stimulation: Its relation to the saccule. *Annals of Otology, Rhinology & Laryngology,* 80, 121–131.

Tsutsumi, T., Tsunoda, A., Noguchi, Y., & Komatsuzaki, A. (2000). Prediction of the nerves of origin of vestibular schwannomas with vestibular evoked myogenic potentials. *The American Journal of Otology,* 21, 712–715.

Tullio, P. (1929). *Das Ohr und die Entstenhung der Sprache und Schrift*. Munchen, Germany: Urban and Scharzenberg.

Versino, M., Colnaghi, S., Callieco, R., & Cosi, V. (2001). Vestibular evoked myogenic potentials: test-retest reliability. *Functional Neuro-otology*, 16, 299-309.

Vivekanandah, M. (2009). Utility of vestibular evoked myogenic potentials in the differential diagnosis of suspected Meniere's disease and Benign Paroxysmal positional vertigo. Unpublished Master's Dissertation. *University of Mysore, India.*

Wang, C. T., & Young, Y. H. (2007). Vestibular-evoked myogenic potentials in chronic noise-induced hearing loss. *Otolaryngol Head Neck Surg*, 137, 607-11.

Wang, C.T., Young, Y.H. (2006). Comparison of the head elevation versus rotation methods in eliciting vestibular evoked Myogenic potentials. *Ear Hear*, 27, 376-81.

Wang, S. J., & Young, Y. H. (2003). Vestibular evoked myogenic potentials using simultaneous binaural acoustic stimulation. *Hearing Research,* 185, 43–48.

Wang, Y. P., Hsu, W. C., & Young, Y. H. (2006). Vestibular evoked myogenic potentials in acute acoustic trauma. *Otol Neurotol*, 27, 956-61.

Watson, S. R. and J. G. Colebatch (1998). Vestibulocollic reflexes evoked by short-duration galvanic stimulation in man. *J Physiol*, 513, 587-97.

Watson, S. R. D., Halmagyi, G. M., & Colebatch, J. G. (2000). Vestibular hypersensitivity to sound (Tullio phenomenon) structural and functional assessment. *Neurology,* 54, 722–728.

Welgampola, M. S., Rosengren, S. M., Halmagyi, G. M., & Colebatch, J. G. (2003). Vestibular activation by bone conducted sound, *Journal of Neurology Neurosurgery Psychiatry*, 74, 771-778.

Welgampola, M. S., & Colebatch, J. G. (2001a). Characteristics of tone burst-evoked myogenic potentials in the sternocleidomastoid muscles. *Otology & Neurotology,* 22, 796–802.

Welgampola, M. S., & Colebatch, J. G. (2001b). Vestibulocollic reflexes: normal values and the effect of age. *Clinical Neurophysiology*, 112, 1971–1979.

Welgampola, M. S., & Colebatch, J. G. (2005). Characteristics and clinical applications of vestibular evoked myogenic potentials. *Neurology*. 64, 1682-1688.

Wu, C. H., & Murofushi, T. (1999). The effect of click repetition rate on vestibular evoked myogenic potential. *Acta Otolaryngologica,* 119, 29–32.

Wu, C., & Young, Y. (2002). Vestibular-evoked myogenic potentials are intact after sudden deafness. *Ear Hear*, 23, 235-38.

Wu, C., & Young, Y. (2004). Vestibular-evoked myogenic potentials in acute low tone sensorineurl hering loss. *Laryngoscope*, 114, 2172-2175.

Yang, Tsung-Lin., & Young, Yi-Ho. (2003). Comparison of Tone Burst and Tapping Evocation of Myogenic Potentials in Patients with Chronic Otitis Media. *Ear and Hearing*, 24, 191-194.

Yang, W. S., Kim, S. H., Lee, J. D., & Lee, W. S. (2008). Clinical significance of vestibular evoked myogenic potentials in benign paroxysmal positional vertigo. *Otology and Neurotology*, 29, 1162-1166.

Yoshie, N., & Okudaira, T. (1969). Myogenic evoked potential responses to clicks in man. *Acta Otolaryngologica (Supplement),* 102, 374–381.

Young, E. D., Fernandez, C., & Goldberg, J. M. (1977). Responses of squirrel monkey vestibular neurons to audiofrequency sound and head vibration. *Acta Otolaryngologica,* 84, 352–360.

Young, Y. H., & Kuo, S. W. (2004). Side-difference of vestibular evoked myogenic potentials in healthy subjects. *Hearing Research,* 198, 93-98.

Young, Y. H., Wu, C. C., & Wu, C. H. (2002). Augmentation of vestibular evoked myogenic potentials: an indication for distended saccular hydrops. *Laryngoscope,* 112, 509-512.

Zapala, D. A., & Brey, R. H. (2004). Clinical experience with the vestibular evoked myogenic potential. *Journal of American Academy of Audiology*, 15, 198–215.

Zhou, G., & Cox, C. L. (2004). Vestibular Evoked Myogenic Potentials: History and Overview. *American Journal of Audiology,* 13, 135–143.

APPENDIX - A

Dizziness Questionnaire

Maryland Hearing and Balance Center

Name _____ Date _____

I. Which of these best describes your dizziness? Circle only one.

- A sensation of movement of yourself or the room: spinning, tilting, or wave-like movement
- Light-headedness or feeling that you are going to faint
- Loss of balance
- Disassociation or disorientation with the world

II. When you are "dizzy" do you experience any of the following sensations? You may circle as many yes responses as necessary.

Yes No 1. Light-headedness or swimming sensation in the head.

Yes No 2. Blacking out or loss of consciousness.

Yes No 3. Tendency to fall.

Yes No 4. Objects spinning or turning around you.

Yes No 5. Sensation that you are turning or spinning inside.

Yes No. 6. Loss of balance when walking

Yes No 7. Headache

Yes No 8. Pressure in the head.

Yes No 9. Nausea or vomiting.

III. Please fill in the blanks or circle appropriate answer

A. When did the dizziness first occur? _____

B. Is the dizziness CONSTANT or does it come in ATTACKS?

C. If the dizziness comes in attacks, how often do these attacks occur? _____ times per day / week / month / year.

D. If the dizziness comes in attacks, how long do the attacks last? _____ seconds / minutes / hours / days.

E. What factors provoke the dizziness or make the dizziness worse? _____

F. What makes the dizziness better?

_____

G. Does your hearing change when the dizziness occurs?

Yes / No How? _____

Which Ear? Right / Left

H. Are there any other symptoms associated with the dizziness, such as visual changes, numbness or tingling in the arms or legs, weakness in the arms or legs, changes in speech?

_____

I. Are you completely free of dizziness between attacks? Circle Yes / No

J. Have you ever been diagnosed with a head or neck injury? Circle Yes / No

K. Do you have any history of a neurological disease such as migraine, multiple sclerosis or stroke? Circle Yes / No

Explain _____

IV. Do you have any of the following symptoms? Please circle *Yes* or No and circle Ear involved.

Yes	No	1. Difficulty in hearing?	Right	Left
Yes	No	2. Noise in your ears?	Right	Left
Yes	No	3. Does noise change during the dizziness? How? _____		
Yes	No	4. Fullness or stuffiness in your ears?	Right	Left

V. Have you experienced any of the following symptoms?

Yes	No	1. Double vision, blurred vision or blindness.
Yes	No	2. Numbness of face.
Yes	No	3. Numbness of arms or legs.
Yes	No	4. Weakness in arms or legs.
Yes	No	5. Clumsiness of arms or legs.
Yes	No	6. Confusion or loss of consciousness.
Yes	No	7. Difficulty with speech.
Yes	No	8. Difficulty with swallowing.
Yes	No	9. Pain in the neck or shoulder.