TEST-RETEST RELIABILITY OF VESTIBULAR EVOKED MYOGENIC POTENTIALS PARAMETERS

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A Dissertation Submitted in Part Fulfilment of Final Year

Master of Science (Audiology)

University of Mysore, Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING,

MANASAGANGOTHRI, MYSORE - 570006

June - 2011

Dedicated

To

Ajja, Ajji, Anna, Amma and my
dearest frenz

CERTIFICATE

This is to certify that this dissertation entitled "***Test-retest reliability of Vestibular Evoked Myogenic Potentials Parameters"*** is a bonafide work submitted in part fulfilment for the degree of Master of Science (Audiology). 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 diploma or degree.

Mysore
June, 2011

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CERTIFICATE

This is to certify that this dissertation entitled “***Test-retest reliability of Vestibular Evoked Myogenic Potentials Parameters”*** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore
June, 2011

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DECLARATION

This is to certify that this master's dissertation entitled "***Test-retest reliability of Vestibular Evoked Myogenic Potentials Parameters***" is the result of my own study under the guidance of **Mr. Niraj Kumar Singh**, Lecturer in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

Mysore **Register No. 09AUD006**

June, 2011

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I am tryin to be as formal as I can be in writing this… but it jus wont be natural if I am formal to thank t ppl tat mattered…. It's a kinda tricky situation wen I am writing this cos I wud not know where to begin, or in this case, who to begin with.. But then again, the famous saint poet KABIR once said

गुरु गोविन्द दोऊ खड़े काको लागूं पायं।
बलिहारी गुरु आपने जिन गोविन्द दियो बताय।।

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CHAPTER-1

INTRODUCTION

An acoustical event of sufficiently high level, when presented to an ear, triggers a series of reflexes. These reflexes may represent short latency, sound-evoked muscle activation (e.g., auropalpebral reflex, stapedial reflex) or inhibitory responses of contracted muscle. Since both vestibular (saccule) and auditory (cochlea) transducers lie close to stapes, it is reasonable to assume that a movement of the stapes may stimulate the cochlea and the vestibule (saccule). One such regularly used “sonomotor” response is the Vestibular Evoked Myogenic Potential (VEMP). Ever since its discovery by Colebatch, Halmagyi and Skuse in 1994, Vestibular evoked myogenic potential (VEMP) testing has been used as a clinical test of vestibular, more specifically, saccular function.

Sound-evoked vestibular responses in humans were described by Von Bekesy (1935) who, using intense sounds of 128 to 134 dB SPL, evoked head movement toward the stimulated ear. Displacement of the stapes footplate, which lies in close proximity to the saccule, was thought to lead to eddy current formation within the endolymph, hair cell displacement, and activation of primary afferents.

Among the vestibular apparatus, the semicircular canals respond to angular acceleration, and the utricle and saccule respond to linear acceleration. Among these organs, it is believed that the saccule is somewhat sensitive to acoustic stimulation. In fishes, it is seen that saccule is the organ of audition and even have a tonotopic representation of the frequencies in the saccule. In evolutionary terms, it has been seen that the present human cochlea evolved into the highly sensitive organ of audition from the rudimentary acoustic functions of the “sacculus” which is seen in lower vertebrates like the fishes and amphibians (Smith, Schuck, Gilley & Rogers, 2011). Hence it can be said that the sensitivity of the saccule to acoustic stimuli is an evolutionary process and that it can still be found in higher mammals like the humans, wherein, a high intensity acoustic stimulus will stimulate the saccule.

McCue and Guinan (1994) made single nerve recordings from the inferior vestibular nerve afferents of cats, which innervate the saccule and posterior semi circular canals and found that there was a significant increase in the discharge rate of the neurons in response to moderately intense (> 80 dB SPL) acoustic signal (clicks & tone bursts). Young, Fernandez and Goldberg (1977) reported that the primary vestibular afferents of squirrel monkeys could respond to sound and vibration. Among the five vestibular end organs, they reported that the saccular macula showed the lowest thresholds, and was best when stimulated using acoustic stimuli less than 1000 Hz. The above studies prove that the saccule is acoustically sensitive and that this forms the basis for the generation of VEMP.

The vestibular system contributes to maintaining the overall balance of the body through three reflexive systems – the vestibulo-ocular, the vestibulo-spinal and the vestibulo-collic reflex systems. The vestibulo spinal reflex system acts in conjunction with the vestibulo-collic reflex system to maintain the overall stability and balance of the body. The system of concern to the generation of the VEMP is the vestibulo-collic reflex

(VCR) pathway (Colebatch, Halmagyi & Skuse, 1994). The function of the reflex is to stabilize the position of the head, and thereby the direction of gaze, in space.

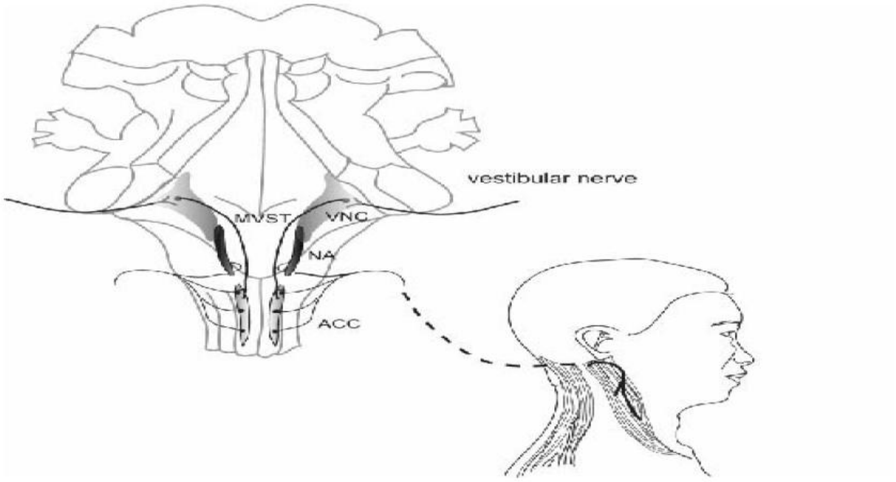


Figure 1.1. Description of the sacculo-collic reflex pathway from the vestibular nucleus to the Sterno-Cleido Mastoid muscle on the neck.

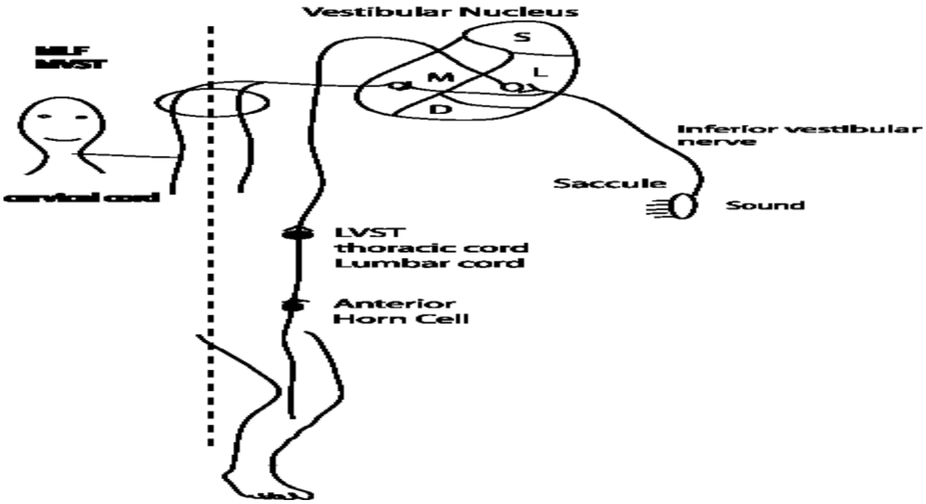


Figure 1.2. Schematic representation of the vestibulo-spinal reflex pathway.

Vestibular-dependent short-latency electromyographic (EMG) responses to intense sound were initially recorded from the posterior neck muscles inserting at the inion (“inion response”) (Bickford, Jacobson & Cody, 1964). Responses were recordable only during activation of the relevant muscles. They were preserved despite sensori-neural hearing loss and abolished in vestibulopathy. Studies performed on selective inner ear lesions identified the saccule to be the responsive end organ (Townsend & Cody, 1971). In humans, intense auditory clicks and/or tone bursts delivered to the ear, either through Air-conduction or Bone-conduction stimulates saccular afferents, leading to inhibition of the sternocleidomastoid (SCM) muscle via the vestibulo-collic pathway (Colebatch et al., 1994). These inhibitory potentials are electromyographically detected with surface electrodes overlying the SCM muscle while the subject maintains tension of that muscle. The resultant waveform consists of an initial positivity or inhibition at about 13 ms post-stimulation, called the “p13” or “P1” potential, followed by a subsequent negativity or excitation at about 23 ms post-stimulation, called the “n23” or “N1” potential.

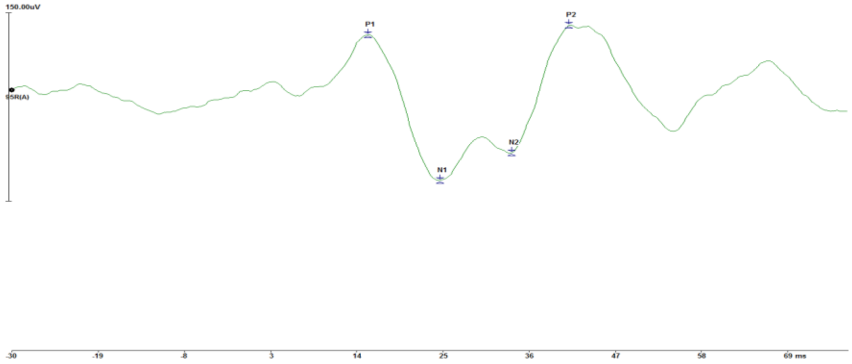


Figure 1.3. A representative waveform of a VEMP response showing all the component peaks.

VEMP responses, thus, give information regarding the saccule and inferior vestibular nerve integrity (Colebatch & Halmagyi, 1994; Robertson & Ireland, 1995). The short-onset latency of the VEMP indicates that it is likely to be mediated by an oligosynaptic pathway, possibly disynaptic and consisting of primary vestibular afferents projecting to the vestibular nuclear complex and then via the medial vestibulospinal tract to the accessory nucleus.

Morphologic and physiologic studies in experimental animals confirm that intense sound selectively activates otolith afferents (McCue & Guinan, 1994, 1995; Murofushi et al., 1995, 1996; Murofushi and Curthoys, 1997). Stimulation of the saccular nerve in cats results in inhibitory postsynaptic potentials in the ipsilateral SCM motor neurons, which travel in the medial vestibulospinal tract (Uchino, Sato & Sasaki, 1997; Kushiro, Zakir, Ogawa, Sato & Uchino, 1999) with only weak effects on the contralateral neurons. Utricular nerve stimulation, in contrast, evokes excitatory postsynaptic potentials in about two-thirds of contralateral SCM neurons. Thus, the predominantly ipsilateral inhibitory SCM responses (e.g., click VEMPs) are likely to represent saccular activation, and prominent crossed responses (observed in direct current [DC] – and tap-evoked VEMPs) may indicate utricular stimulation. So, VEMPs are currently and popularly being recorded using symmetric sites over the sternocleidomastoid (SCM) muscle (Colebatch et al., 1994).

The clinical application of VEMP has recently been expanding in the field of audiology and otology. Most clinical tests of vestibular assessment evaluate only the semicircular canals and the superior vestibular nerve. Till date, VEMP stands to be the only and the most sensitive test to identify the lesions of saccule and/or the inferior vestibular nerve. VEMP has found its application in the differential diagnosis of different disorders like Meniere's disease, Vestibular Schwannoma, Vestibular neuritis, Superior semicircular canal dehiscence syndrome, etc. VEMP has also been found to be useful in monitoring the effects of Gentamicin treatment. Also, the fact that VEMP responses can be present in even the face of a significant sensori-neural hearing loss has made its application that much more meaningful. Furthermore, recording VEMP through the BC mode has helped in identification of vestibular problems even in the presence of a major conductive hearing loss.

Need for the study

Any clinical tool must be reliable for it to be used efficiently. Therefore normative data regarding the reliability of any clinical tool is essential. Previous researches have indicated that the test-retest reliability for VEMP, in general, has been good – most studies indicating fair to excellent reliability. However, there are still inconsistencies with regard to many of the VEMP parameters. For instance, among others, Nguyen, Welgampola and Carey (2010) reported good reliability values for peak-to-peak amplitudes, P1 amplitudes, N1 latencies and asymmetry ratios. But other parameters like the P1 latency and N1 amplitude were found to be only moderately reliable. Isaradisaikul, Strong, Moushey, Gabbard, Ackley and Jenkins (2008) also reported inconsistencies in the reliability measures of VEMP parameters like the latency parameters (both intra-aural & inter-aural) and the latency-intensity function, especially the thresholds for VEMP. The inconsistencies across the studies may be attributed to the inadequate number of participants considered for a normative study.

VEMP can be recorded through air- and bone- conduction stimuli. Till date, no study has evaluated the test-retest reliability of a bone conducted VEMP. In addition, the recording of VEMP for AC stimuli in subjects with conductive hearing loss is not appropriate. Hence, the need arises to establish separate reliability values for AC and BC modes of VEMP recording.

Previous investigations regarding the effect of stimulus level on the latency and amplitude measures of VEMP responses have indicated many inconsistencies. Furthermore, there are few studies which have compared the latency-intensity functions and amplitude-intensity functions for AC- and BC- stimuli. Therefore, it becomes necessary to compare the effect of stimulus presentation level on AC- and BC- VEMP.

VEMP can be recorded with or without a feedback mechanism for monitoring the tension on the SCM muscle. Various studies (Maes, Vinck, De Vel, D’haenens, Bockstael, Keppler, Phillips, Swinnen & Dhooge 2009; Isaradisaikul et al., 2008) have been published regarding the reliability of both these procedures. However, a lot of inconsistencies have been reported in the reliability values for both the procedures, with values ranging from poor to good for the different VEMP parameters considered. Also, various other methods have been used to monitor the tension of the SCM muscle like using a blood-pressure manometer (Isaradisaikul et al., 2008) as a feedback mechanism. The unavailability of such devices in regular audiological clinics becomes a major drawback when using such devices. There is a need to have an alternative apparatus that could be aiding to the reliability, at the same time should also be easily fabricable. However, the reliability of such an apparatus needs to be established before using it clinically. Also, a comparison of the reliability of the rectified and the unrectified (using the alternative apparatus) procedures needs to be made to highlight their use interchangeably. Hence, there is a need to establish separate reliability norms for rectified and unrectified procedures.

Aim of the study

The present study primarily aimed at evaluating the test-retest reliability of VEMP using the rectified and unrectified procedure through AC- and BC- mode. The present study also aimed at studying the effect of stimulus intensity on the different VEMP parameters when recorded using AC- and BC- stimulation for the rectified and unrectified methods.

Objectives of the study

The specific objectives of the study were

1. To evaluate and compare the test-retest reliability of Rectified and Unrectified VEMP parameters using AC and BC stimuli at the highest intensity and at threshold.
2. To evaluate and the test-retest reliability of VEMP thresholds for AC- and BC- modes of stimulation in the rectified and unrectified conditions.
3. To study the effects of intensity on the different response parameters of VEMP.

CHAPTER-2

REVIEW OF LITERATURE

Among VEMP studies in normal subjects, as well as in hearing impaired subjects, a variety of response parameters have been investigated in the last decade. These include Absolute amplitude of the peaks, Peak latencies, Inter-peak latencies, VEMP thresholds, Asymmetry ratio ($\{AR = 100 \mid (A_L - A_R)/ (A_L + A_R)\mid\}$) etc. The recording procedures and the protocols for VEMP have also been keenly studied. The major factors that influence the results of the VEMP testing include the type of stimuli used (Tone burst Vs Click), mode of stimulation (Air-conduction Vs Bone conduction), level of the stimulus, frequency of stimulus, rise/fall time and the plateau time of the stimulus, the method of monitoring the tension (EMG) on the SCM muscle, etc.

Type of stimulus

VEMP recording has been done using both clicks and short duration tone bursts presented through earphones. It is generally agreed that click evoked VEMP can be obtained for stimulus intensities of about 90 dBnHL. Welgampola and Colebatch (2001) reported that tone-burst evoked myogenic responses were similar to click evoked responses but required lower stimulus intensities. But it has to be noted that tone bursts might evoke both the utricular and the saccular hair cells simultaneously, whereas clicks only evoke the saccular part (Murofushi & Curthoys, 1995; 1997). Kumar, Sinha, Bharati and Barman (2011) compared the VEMPs elicited by clicks and short duration tone bursts and found delayed latencies and higher amplitudes for the tone bursts compared to clicks (for P1 & N1).

Stimulus frequency

Townsend and Cody (1971) were among the first to report that the activity from the neck muscles in response to a loud acoustic stimulus was maximum in its amplitude for 250- and 500 Hz stimuli. Akin and associates (2003) showed a “frequency tuning” feature with the largest amplitude at either 500 Hz or 750Hz. Todd, Cody and Banks (2000) confirmed frequency tuning in VEMPs; however, they found that the maximum response was at frequencies between 300 and 350 Hz. Hence it can be seen that a low-frequency tone burst (300 -750 Hz) stimuli elicit the largest VEMP responses, when the other stimulus parameters (like the rise/fall time, plateau & intensity) are kept constant.

Mode of stimulation

Similar to air-conducted clicks and tone bursts, skull taps and bone conducted clicks and tone bursts can also be used to bypass the middle ear conductive apparatus and elicit VEMPs from the SCM muscles despite a significant conductive hearing loss (Sheykholeslami, Murofushi, Kermany, & Kaga, 2000; Welgampola, Rosengren, Halmagyi, & Colebatch, 2003). A forehead tap, delivered at F_{pz} (International 10–20 System) via a tendon hammer, evokes a vestibular dependent short-latency p1-n1 response in both SCMs (Halmagyi, Yavor & Colebatch, 1995). A bone-conducted tone burst delivered over the mastoid process, via a bone vibrator, routinely used in audiometric testing, evokes VEMPs despite conductive hearing loss (Sheykholeslami, et al., 2000; Welgampola, et al., 2003). VEMPs, thus recorded are often bilateral, as the stimulus is transmitted via bone and activates end organs on both sides. The ipsilateral VEMP is about 1.5 times larger and occurs approximately 1 millisecond earlier. Galvanic stimulation (short duration-pulsed current delivery) has also been used to evoke VEMPs (Watson and Colebatch, 1998).

Placement of bone vibrator

Welgampola, Rosengren, Halmagyi (2003) compared different bone vibrator placements – mastoid, frontal, occipital and anterior temporal sites. They reported that in general, the VEMP to BC stimulation occurred more consistently when the bone vibrator was placed on the mastoid, although the highest amplitudes were obtained when the bone vibrator was placed 3cm posterior to and 2cm rostral to external auditory meatus.

Level of stimulus

VEMP response amplitude is directly proportional to stimulus intensity (Colebatch, Halmagyi, & Skuse 1994). VEMP amplitude decreases with a decrease in stimulus level and disappears at about 90 to 100 dB SPL, whereas VEMP latency is independent of the stimulus level (e.g., Akin et al., 2003). Colebatch et al., (1994) found that the thresholds for click evoked VEMP was in the range of 75 – 85 dB nHL (for the P1-N1 complex).

Muscle tension

VEMP amplitudes show strong correlations with the extent of muscle contraction. Increased tension in the neck muscles produced a major increase in amplitude, whereas muscle relaxation abolished the responses (Lim, Clouston, Sheean, & Yiannikas, 1995). Muscle tension (on the SCM) is usually maintained/ monitored by asking the subject to press their forehead against a bar (for bilateral SCM contraction) or by keeping the subject's head rotated either to the left or the right side (for unilateral SCM contraction) (Colebatch et al., 1994).

As VEMP amplitudes show strong correlations with the extent of muscle contraction, efforts to minimize the effects of muscle contraction fluctuation may be required. This has three functions:

(1) To ensure adequate levels of activation,
(2) To enable fine adjustment of head position to match the EMG levels for each side and
(3) To allow measurement of background contraction levels and calculation of normalized amplitudes

To correct VEMP amplitudes, an average of rectified background muscle activity during a prestimulus period of 20 ms is used (Welgampola & Colebatch, 2001). The corrected amplitude (CA) of VEMP is defined as a ratio –

$$CA = (\text{raw amplitude of } P1–N1)/ (\text{mean background amplitude})$$

For this purpose, one must average the rectified EMG during a pre-stimulus period. But it has been noted that the VEMP is best visualized in using an averaged unrectified EMG.

Other methods to monitor the neck muscle tension have also been used like using pressure cuffs on the neck to enable the subject and/or the tester to monitor the muscle tension online, during the testing. These methods utilize direct control of the magnitude of the neck muscle by monitoring and maintaining the amplitude of the EMG at a constant target level (usually a level between 50 to 200 µV, as prescribed by Young, 2006) during the activation of the SCM muscle (Colebatch et al., 1994; Lim et al., 1995; Murofushi, Matsuzaki, & Chih-Hsiu 1999; Todd, Cody, & Banks, 2000; Akin & Murnane, 2001).

From the above mentioned information, it can be inferred that VEMP responses can be affected by a large number of stimulus and recording related factors and it becomes highly necessary that these factors should be controlled when recording VEMP, especially for a clinical interpretation.

Reliability of VEMP

Many recent studies have been done to investigate the test-retest reliability of most of the response parameters of VEMP under different conditions like rectified Vs unrectified, AC- Vs BC- stimuli etc.

Isaradisaikul et al. (2008) measured the test-retest reliability of VEMP in 20 people with normal audio-vestibular functioning, with and without the use of electromyographic (EMG) monitoring. Prospective evaluations of the VEMP responses were done and without the use of (EMG) monitoring in two separate sessions, 1 to 4 weeks apart. The threshold repeatability, P1 and N1 latency, P1 and N1 inter-peak latency, peak to peak amplitude and the interaural amplitude difference from the first and second sessions were assessed via the interclass correlation coefficient (ICC). The test-retest reliability of P1-N1 peak to peak amplitude was found to be excellent and the reliability of the threshold and latency measures were found to be fair to good, with the exception of poor reliability for P1 latency in the EMG monitoring condition. Overall, the VEMP response parameters were found to have fair to good test-retest reliability. The ICC was found to be more reliable for the amplitude measures than for the latency measures, with the latency of N1 being more reliable than the latency of P1. The repeatability of threshold, P1-N1 peak to peak amplitude and interaural difference ratio was found to be higher with EMG than without EMG.

Vanspauwen, Wuyts and Van de Heyning (2009) conducted a study on 30 normal subjects to determine the normal limits and to analyse the test-retest reliability of VEMP parameters. The VEMP responses were recorded unilaterally by asking the subjects to turn their heads away from the side of stimulation and monitoring their SCM muscle contraction level based on a dial on the computer screen. The VEMP procedure was repeated on different days to analyse test-retest differences. The different reliability parameters calculated were interclass reliability coefficient (ICC), method error (ME), coefficient of variation of method error (CV_{ME}), standard error of measurement (SEM) and minimal difference (MD). Normal values for left-right differences, based on interaural ratio (IAR), were also determined. For each VEMP parameter, the ICC values indicated excellent reliability, except for P1 and corrected amplitude (fair to good reliability). The CV_{ME} values were less than 7% for P1, N1 threshold, $MRV_{females}$ (mean rectified voltage for females) and MRV_{males} (mean rectified voltage for males). For the parameters – corrected amplitude and raw amplitude, the CV_{ME} values exceeded 15%. The 95% IAR prediction intervals (PIs) were also largest for the parameters raw amplitude and corrected amplitude.

Maes et al. (2009) considered 61 healthy normal hearing subjects to evaluate the reliability of VEMP responses in clinical setting when only a feedback mechanism is available for monitoring the EMG. Of the 61 subjects, 14 subjects were retested after one week to assess the test-retest reliability. VEMPs were recorded using 500 Hz tone bursts with the subjects in a sitting position and their heads turned away from the test ear to the contralateral shoulder, thereby pushing their chin against the inflatable cuff of a blood pressure manometer, serving as a feedback method. Results indicated that the feedback method revealed latency and amplitude values comparable to the other data in the literature where different test conditions were applied. Excellent reliability, with ICC values ranging from 0.78 to 0.96, and CV_{ME} values ranging from 4% to 36% was achieved for P1 and N1 latencies, threshold and interpeak amplitude. Good reliability, with ICC values of 0.65 and 0.68 and CV_{ME} values of 170% and 189%, was obtained for the asymmetry ratio. It was finally concluded that a unilateral muscle contraction controlled by a feedback mechanism resulted in reliable response parameters. Hence the use of a blood pressure manometer as a feedback mechanism provides a reliable alternative in clinical settings, when the background muscle contraction cannot be measured or software related correction algorithms are not accessible.

Nguyen et al. (2010) determined the test-retest reliability of cervical VEMP responses to air- and bone- conducted stimulation in 53 healthy adults with no history of audiological and/or vestibular problems. All subjects underwent cVEMP testing in response to sounds (clicks and tone bursts) and vibration (midline forehead taps at the F_z position with a reflex hammer) when the subjects were asked to lift their heads from the headrest to maintain the neck muscle tension. 12 subjects underwent an additional testing session that was conducted at a mean of 10 weeks after the first one. The main outcome measures evaluated were test-retest reliability for VEMP response parameters (latency, peak-to-peak amplitude, and asymmetry ratio) and these were assessed using the interclass correlation coefficient. Results of cVEMP showed that amplitudes had excellent reliability for hammer taps and fair to good reliability for the other stimuli. cVEMP asymmetry ratios had fair to good reliability for clicks and hammer taps.

CHAPTER-3

METHOD

Subject selection criteria

80 participants were divided into three groups with equal number of males and females in each group. Group 1 consisted of individuals from 18 to 25 years, group II involved individuals from 25 to 35 years and group III consisted of 35 to 45 year old subjects. All participants were required to have pure tone thresholds within 15 dBHL in the octave frequencies of 250 through 8000 Hz for AC and 250 through 4000 Hz for BC stimuli, normal middle ear functioning, and no complaint or history of symptoms related to vestibular pathologies.

Instrumentation

(1) Madsen Orbiter-922 type I diagnostic audiometer with TDH-39 supra-aural earphones housed in MX-41 ear cushions and Radio ear B-71 bone vibrator were used to estimate the air- and bone-conduction thresholds respectively.

(2) Grason Stadler Inc. – Tympstar clinical immittance meter was used to rule out middle ear pathology.

(3) Intelligent Hearing Systems Smart EP version 4.0 evoked potentials system with ER-3A insert earphones and Radio ear B-71 bone vibrator was be used for the recording of air- and bone- conducted VEMP responses respectively.

Procedure

All participants underwent otoscopic evaluations in order to rule out any outer ear and/or tympanic membrane pathologies. Pure tone audiometry was done using the Carhart and Jerger - modified Hughson-Westlake procedure (1959) for the octave frequencies of 250 through 8000Hz for air-conducted stimuli using the TDH-39 headphones. Bone conduction sensitivity was measured for the octave frequencies of 250 through 4000 Hz. Immittance evaluation was done to rule out any middle ear pathologies. Tympanometry was done using a 226 Hz probe tone. Ipsilateral and contralateral acoustic reflex thresholds were measured at 500 through 4000 Hz. VEMP were recorded for both the ears of all the participants. The participants were seated comfortably with their head turned away from the ear of stimulation. A default delay of 0.8 ms was incorporated by the default settings of the IHS instrument to correct for the delay caused by the use of tubing for the insert earphones. The recordings were done under two conditions:

- Unrectified
- Rectified

For the unrectified procedure, the tension on the SCM muscle was monitored by using a specially fabricated apparatus as shown in the figure 3.1. SCM muscle tension was considered appropriate when the subject touched the board with the lateral side of his/her chin while turning his/her head. The apparatus was also fabricated in such a way that it would guard against any movement of the shoulders during the recording.

Figure 3.1. Recording of unrectified VEMP from one of the participants using the specially fabricated apparatus. (Photographs were obtained with informed consent of the participant).

Figure 3.2. Recording of rectified VEMP from one of the participants using the visual feed-back mechanism. (Photographs were obtained with informed consent of the participant).

For the rectified procedure, the SCM muscle tension was monitored by a visual feedback system which is already an inbuilt component of the IHS EP system as shown in figure 1.5. In this, a green light indicates appropriate tension and a yellow light appropriate insufficient tension.

Recording protocol for VEMP

Table 3.1:

Recording protocol for air-conduction VEMP.

Stimulus parameters	Acquisition parameters
Stimulus frequency: 500 Hz tone burst **Stimulus duration:** 2-1-2 cycle (equivalent to 10ms total duration) **Stimulus intensity:** 95 dBnHL or variable intensities (5 dB step size) **Transducer:** ER-3A Insert earphones (300Ω) **Repetition rate:** 5.1/s **Number of sweeps:** 150 **Polarity:** Alternating	**Electrode montage:** *Non-inverting*: 2/3rd of the distance of the insertion of the Sterno-cleido-mastiod muscle, on the ipsilateral side of the test ear *Inverting electrode*: Sterno-clavicular junction *Ground electrode*: Low forehead. **Absolute electrode impedance:** < 10 kΩ **Inter-electrode impedance**: < 2 k Ω **Amplifier gain:** 5000 times **Time window for recording:** 70 ms **Filter settings:** band pass of 10 to 1500 Hz

Table 3.2:

Recording protocol for bone-conduction VEMP.

Stimulus parameters	**Acquisition parameters**
Stimulus frequency: 500 Hz tone burst **Stimulus duration:** 2-1-2 cycle (equivalent to 10ms total duration) **Stimulus intensity:** 95 dBnHL or variable intensities (5 dB step size). **Transducer:** ER-3A Insert earphones (300Ω) **Repetition rate:** 5.1/s **Number of sweeps:** 150 **Polarity:** Alternating	**Electrode montage:** *Non-inverting*: 2/3rd of the distance of the insertion of the Sterno-cleido-mastiod muscle, on the ipsilateral side of the test ear *Inverting electrode*: Sterno-clavicular junction Ground electrode: Low forehead. **Absolute electrode impedance:** < 10 kΩ **Inter-electrode impedance**: < 2 k Ω **Amplifier gain:** 5000 times **Time window for recording:** 70 ms **Filter settings:** band pass of 10 to 1500 Hz

Each subject was tested on two different days within a week of each other with a minimum gap of one day using the protocols mentioned in tables 3.1 and 3.2 for AC- and BC- VEMP respectively. Also a brief case history was taken to avoid adulteration of data due to any vestibular pathologies that might have crept in the gap between the test and retest period. Two recordings were done at each level in all the conditions with a rest period of two minutes between each recording. The recordings were randomized with respect to the intensity (depending on the transducer), transducer (AC Vs BC), ear (right Vs left) and the procedure (rectified Vs Unrectified) used. The parameters measured included

(1) Absolute amplitudes of P1 and N1
(2) Peak to peak amplitude of the P1-N1 complex
(3) Absolute latencies of P1 and N1
(4) P1-N1 inter-peak latency difference
(5) Latency-Intensity function
(6) Amplitude-Intensity function
(7) Inter-aural latency and amplitude differences
(8) Asymmetry ratio using the following formula:

$$[AR = 100 \mid (AL - AR)/AL + AR)\mid]$$

All the above evaluations were carried out in an air-conditioned, well illuminated room with the noise levels well within the permissible levels as per the ANSI S3.1-1991.

CHAPTER-4

RESULTS

In the present study, VEMP recordings were done on a total of 80 audiologically and otologically normal participants, out of which a retest could be done on only 65 subjects. Among the 80 subjects, 5 had complete unexplained absence of VEMP bilaterally. To achieve the aims of the study, the following statistical tools were used using the SPSS software (version 19).

- Descriptive statistics (mean & standard deviation) was done for different VEMP parameters.
- The Cronbach's alpha test was used to evaluate the test-retest reliability of different VEMP parameters, both at the maximum levels as well as at the threshold.

The results obtained after statistical analysis of the data were as follows:

Effect of stimulus level on VEMP parameters

The VEMP recordings were done in the rectified and unrectified conditions using AC- and BC- stimulation. The testing was started at 95 dB nHL and 70 dB nHL (for the AC & BC modes respectively) and reduced in 5 dB steps until the VEMP threshold was reached. The VEMP threshold was defined as the lowest stimulus level at which the VEMP waveforms could be reproducibly recorded. The parameters considered were P1 latency, P1 amplitude, N1 latency, N1 amplitude, P1 – N1 amplitudes, the inter-peak latency differences, and the inter-aural latency differences for the P1 and N1 peaks. A representative set of waveforms of the VEMP recordings for the changes in stimulus levels from one of the participants of the study is shown in figure 4.1

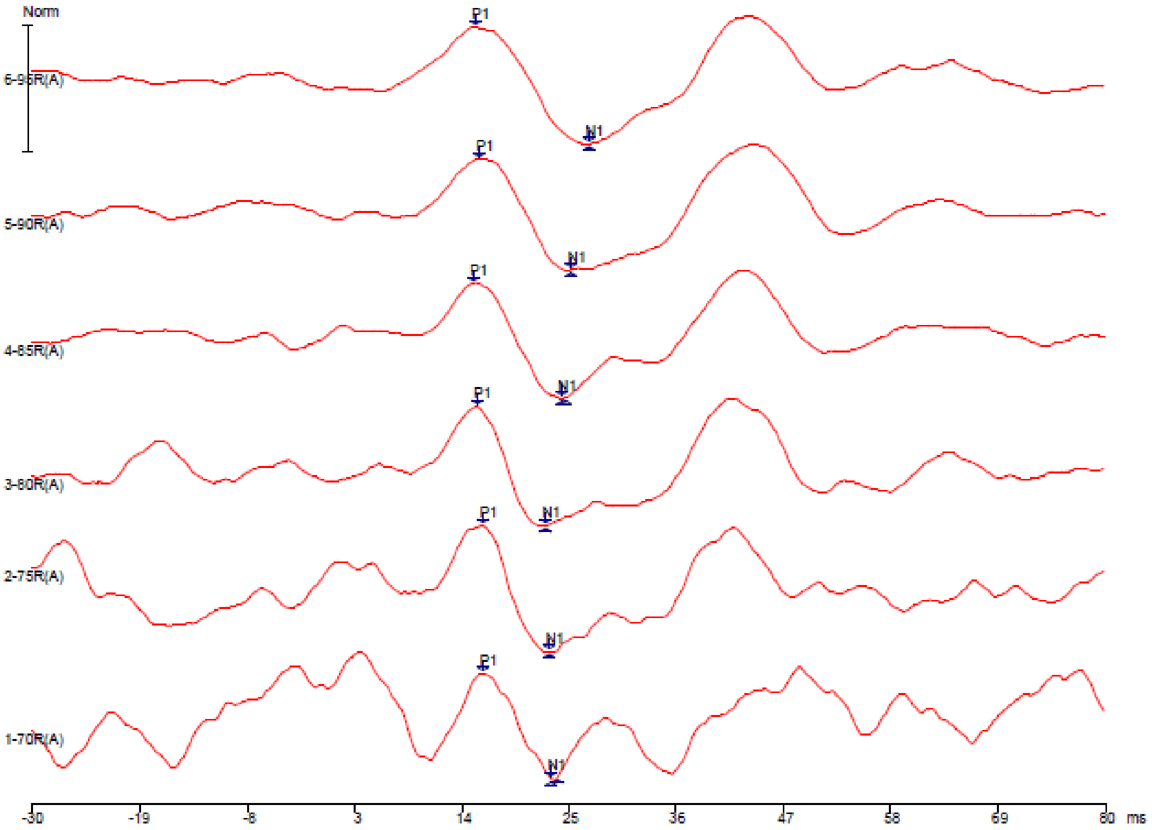


Figure 4.1. A representative set of waveforms obtained from one of the participants. The figure depicts the changes in the VEMP parameters when measured at different intensities.

a. Rectified VEMP

Rectified VEMPs were recorded in each of the subjects by having them monitor the tension in the SCM using a visual feedback system. The muscle tension was maintained between 100- and 200 % of the original muscle tension which corresponded to a range of 50 to 200µV. Table 4.1 depicts the effect of intensity on P1 and N1 latency for the right and left ears. A general trend towards increase in latencies of P1 and N1 with increase in stimulus level can be seen from the table although statistical analysis using the paired t-test yielded no statistically significant difference ($p > 0.05$) for the latencies at 95 dB n HL and at the threshold for both P1 and N1 peaks. The same can also be seen in figure 4.2. The inter-peak and inter-aural latency differences (not mentioned in the table) for both the ears were also measured. The inter-peak latencies were found to be 7.19 (SD±2.09) and 7.12 (SD±1.88) for the right and left ears respectively. The inter-aural latency difference was found to be 1.45 (SD±1.45) for the P1 and 1.50 (±1.61) for the N1 peak.

Table 4.1

Mean and SD of P1 and N1 latencies at different intensities for right and left ear – rectified AC condition.

	Right				Left			
	P1		N1		P1		N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
95	15.31	2.13	22.50	2.16	15.45	2.18	22.57	1.80
90	15.55	2.11	22.21	2.03	15.47	2.15	22.46	2.02
85	15.33	2.28	22.01	2.11	15.60	2.20	21.90	2.11
80	15.20	2.40	21.53	2.19	15.28	2.11	21.32	2.17
75	15.37	2.65	21.15	2.28	15.48	2.47	21.31	2.69
70	14.21	1.17	20.23	1.81	14.81	1.25	20.78	2.21

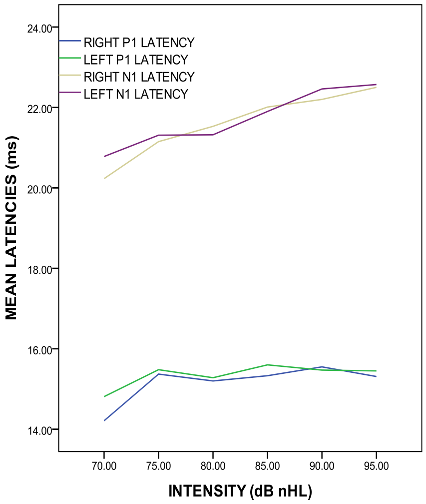


Figure 4.2. Effect of intensity on mean rectified P1and N1 latencies– AC mode

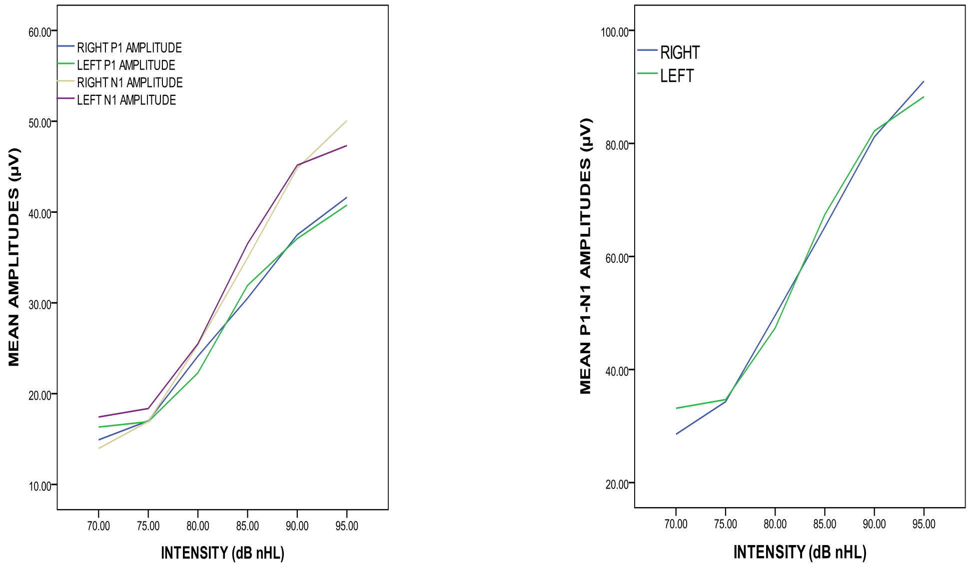
Table 4.2 shows the effect of stimulus level on the amplitudes of P1 and N1 peaks. It can be seen from the table that the P1 and N1 peaks show a trend towards increase in amplitude with increase in intensity. This trend can be observed in figure 4.3 (a). A comparison of the curves for the P1 and N1 amplitudes revealed marginally steeper slopes of the N1 curve.

Table 4.2 also depicts the effect of stimulus levels on mean P1-N1 amplitudes. Similar to the P1 and N1 amplitudes, a trend towards increase in the P1-N1 amplitude can be seen with increase in the stimulus intensity level. The same trend can also be observed in figure 4.3 (b).

Table 4.2.

Mean and SD of P1, N1 and P1-N1 amplitudes at different intensities for right and left ear – rectified AC condition.

	Right						Left					
	P1		N1		P1-N1		P1		N1		P1-N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
95	41.62	20.27	50.07	26.13	91.02	43.15	40.76	20.19	47.32	21.14	88.26	38.28
90	37.49	18.78	43.87	19.44	81.15	35.30	37.07	16.79	45.16	19.75	82.21	33.89
85	30.51	14.32	34.95	16.84	65.19	28.48	31.92	16.42	36.52	17.25	67.40	30.66
80	24.13	14.59	25.40	15.07	49.58	26.31	22.29	13.98	25.50	14.37	47.35	26.27
75	17.00	10.31	16.93	9.58	34.31	15.77	16.91	10.48	18.36	11.87	34.68	19.81
70	14.91	6.80	13.96	8.70	28.55	12.84	16.32	8.20	17.43	9.64	33.15	14.80



(a) (b)

Figure 4.3. Effect of intensity on mean rectified amplitudes– AC mode. (a) Effect of intensity on mean P1 and N1 amplitudes; (b) Effect of intensity on mean P1-N1 amplitude.

Descriptive statistics was done for the BC- VEMP parameters measured in the rectified mode. The mean and SD of the different VEMP parameters were found for both right and left ears for the rectified method. The BC-VEMPs were absent for 21 of the ears (12 subjects in the right ear & 9 subjects in the left ear) which corresponded to a prevalence of 86%. Tables 4.3 and 4.4 depict the BC- VEMP at different stimulus levels. Table 4.3 did not reveal any clear trend for P1 and N1 latencies with increase in intensity from 60 to 70 dB nHL. Statistical analysis using the paired t-test also yielded no statistically significant difference (p > 0.05) for both P1 and N1 peaks. The same can be seen in figure 4.4. The mean inter-peak and inter-aural latency differences (not mentioned in the table) for both the ears were also measured. The inter-peak latencies were found to be 6.52 (SD±2.08) and 6.26 (SD±1.82) for the right and left ears respectively. The inter-aural latency difference was found to be 1.54 (SD±1.44) for the P1 and 2.11 (±1.71) for the N1 peaks.

Table 4.3:

Mean and SD of P1 and N1 latencies at different intensities for right and left ear – rectified BC condition.

	Right				Left			
	P1		N1		P1		N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
70	15.37	2.49	21.90	2.62	15.25	2.34	21.51	2.13
65	16.03	2.26	22.30	2.08	15.39	2.10	21.41	2.18
60	15.37	2.10	21.75	2.49	14.50	1.31	20.07	0.92

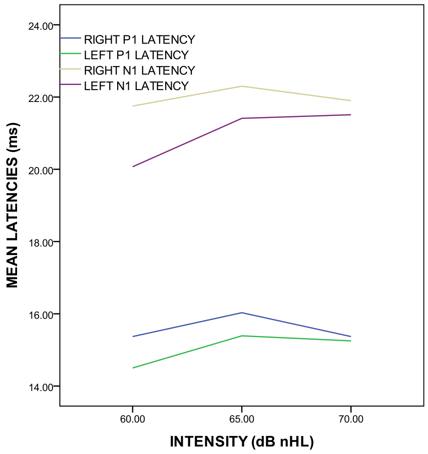
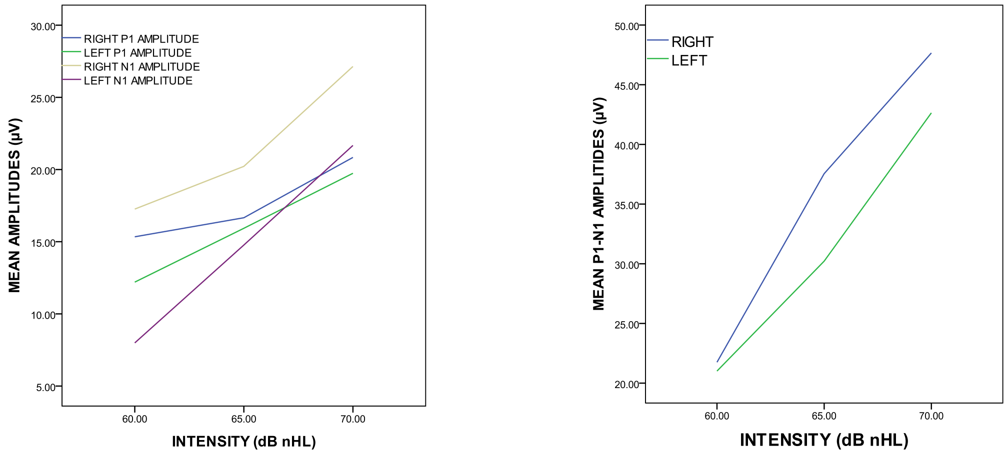


Figure 4.4. Effect of intensity on mean rectified P1and N1 latencies – BC mode.

Unlike the latencies, the amplitudes of the peaks showed a clear trend for the BC-VEMPs. This trend has been shown in table 4.5 (a) and figure 4.5 (b). It can be seen that the amplitudes of P1 and N1 show an increase with increase in stimulus levels.



(a) (b)

Figure 4.5. Effect of intensity on mean rectified amplitudes – BC mode. (a) Effect of intensity in P1 and N1 amplitudes; (b) Effect of intensity in P1-N1 amplitude.

The effect of stimulus intensity on P1-N1complex is shown in figure 4.4 (b). The figure reveals a trend that is similar to the individual component peaks P1 and N1.

Table 4.4.

Mean and SD of P1, N1 and P1-N1 amplitudes at different intensities for right and left ear – rectified BC condition

	Right						Left					
	P1		N1		P1-N1		P1		N1		P1-N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
70	20.84	12.51	27.14	15.75	47.66	25.98	19.74	11.96	21.67	13.03	42.64	24.60
65	16.66	10.79	20.22	12.93	37.35	21.68	15.93	10.07	14.77	7.16	30.22	12.17
60	15.34	7.76	17.26	9.16	32.49	14.06	12.20	2.58	7.99	8.34	21.01	6.86

b. Unrectified VEMP

All the above results were measured using the rectified method. The same measurements were made using the unrectified method. For the unrectified method, the tension of the SCM muscle was considered appropriate when the subject touched the lateral side of his/her chin to a reference point on the apparatus (as shown in figure 3.1). Tables 4.5 and 4.6 depict the unrectified VEMP parameters as a function of intensity in the AC mode.

Table 4.5 shows the effect of intensity on the latencies of P1 and N1. It can be seen from the table that P1 latencies did not appear to show any change with increase in intensity, except at the threshold. However, N1 latencies appeared to show a slightly increasing pattern with increase in stimulus level. The same can be seen from figure 4.6. Statistical analysis using the paired t-test yielded no statistically significant difference ($p > 0.05$) for both the P1 and N1 latencies. The inter-peak latency differences (not shown in the table) were 6.97 (SD±1.90) and 7.06 (SD±1.60) for the left and right ears respectively. Comparison for each peak between the ears showed the inter-aural latency differences to be 1.60 (SD±1.49) and 1.91 (SD±1.66) for the P1 and N1 peaks respectively.

Table 4.5:

Mean and SD of P1 and N1 latencies at different intensities for right and left ear – unrectified AC condition.

	Right				Left			
	P1		N1		P1		N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
95	15.29	2.14	22.35	1.89	15.57	2.27	22.54	2.25
90	15.25	2.22	22.31	1.90	15.705	2.27	22.32	2.38
85	15.20	2.10	21.81	1.95	16.00	4.72	21.62	10.44
80	15.11	2.29	21.42	2.14	15.65	2.90	21.69	7.31
75	14.97	2.58	21.07	2.54	15.00	2.21	21.04	2.12
70	13.93	1.26	20.01	1.45	14.90	1.58	20.23	2.20

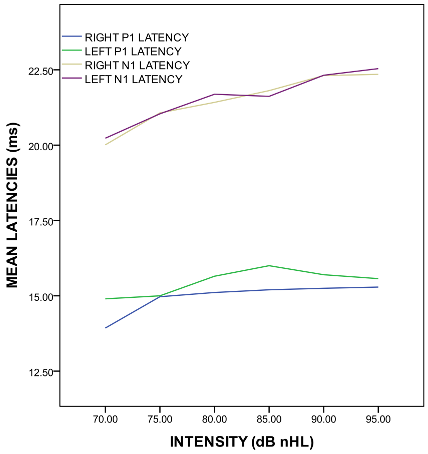
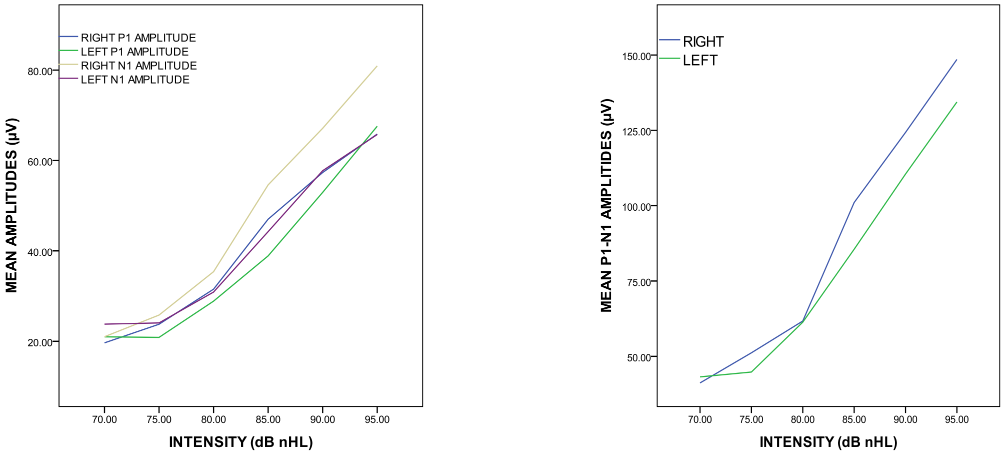


Figure 4.6. Effect of intensity on mean unrectified P1and N1 latencies – AC mode.

Table 4.6 depicts the effect of stimulus levels on mean P1 and N1 amplitudes. It can be seen from the table that the mean P1 amplitudes show an increase in amplitude with corresponding increase in the stimulus intensities. The function appears nearly linear as can be seen from figure 4.7 (a).

Figure 4.7 (b) shows the effect of intensity on mean P1 – N1 amplitudes. It can be seen from the figure that the amplitudes increase with increase in stimulus levels almost linearly for both the ears. The mean amplitudes measured using the unrectified method was higher than the rectified method at all intensitites, as a result giving rise to an evidently steeper slope for the unrectified curves compared to the rectified curves.



(a) (b)

Figure 4.7. Effect of intensity on mean unrectified amplitudes – AC mode. (a) Effect of intensity on P1 and N1 amplitudes; (b) Effect of intensity on P1-N1 amplitude.

Table 4.6:

Mean and SD of P1, N1 and P1-N1 amplitudes at different intensities for right and left ear – unrectified AC condition.

	Right						Left					
	P1		N1		P1-N1		P1		N1		P1-N1	
Intensity (dB n HL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
95	68.55	45.97	80.93	55.12	148.54	98.20	67.58	59.84	65.74	47.47	134.41	93.87
90	57.34	31.61	67.12	39.65	124.32	68.52	52.94	37.22	57.74	39.31	110.50	75.18
85	47.01	32.54	54.60	35.78	101.05	65.11	38.89	28.26	44.26	35.22	85.84	53.74
80	31.53	21.55	35.40	19.96	61.72	44.91	28.88	21.26	30.89	23.11	61.34	39.34
75	23.77	13.57	25.80	16.26	51.17	25.33	20.86	17.07	24.06	18.27	44.79	33.34
70	19.65	7.39	21.01	9.36	41.17	12.18	20.98	12.14	23.79	17.24	43.18	26.46

BC VEMPs were recorded at different intensities for the unrectfied method. The parameters measured were the same as those of rectified BC VEMP. Tables 4.7 and 4.8 depict the BC- VEMP parameters as a function of stimulus intensity for the unrectified method.

Table 4.7 shows the effect of intensity on P1 and N1 latencies for the unrectified BC- VEMP. The table shows a tendency for the P1 latencies to marginally increase with the increasing stimulus levels. The N1 latencies, however, appeared to remain nearly constant with increase in stimulus intensity. This trend can be seen from figure 4.8. Statistical analysis using the paired t-test yielded no statistically significant difference ($p > 0.05$) for both P1 and N1 peaks. Grossly, it can be said that both P1 and N1 latencies remained unchanged with increase in the stimulus levels, marginal vagaries notwithstanding. The inter-peak latency differences (not shown in the table) were 6.24 (SD±1.80) and 5.96 (SD±1.82) for the left and right ears respectively. Comparison for each peak between the ears showed the inter-aural latency differences to be 1.93 (SD±2.05) and 1.90 (SD±1.34) for the P1 and N1 peaks respectively.

Table 4.7:

Mean and SD of P1 and N1 latencies at different intensities for right and left ear – unrectified BC condition.

	Right				Left			
	P1		N1		P1		N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
70	15.56	2.55	21.81	2.32	15.56	2.60	21.41	2.49
65	15.27	1.99	21.32	1.89	16.24	5.14	21.13	2.62
60	14.20	1.26	21.35	2.29	15.25	3.29	21.45	1.95

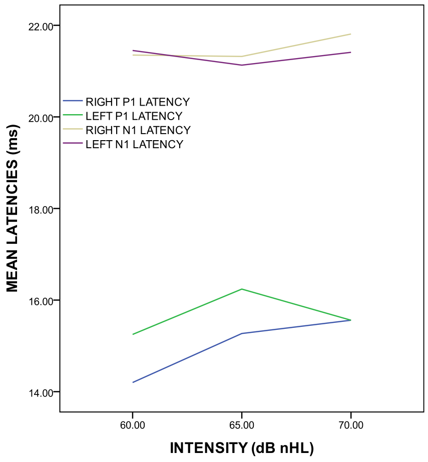
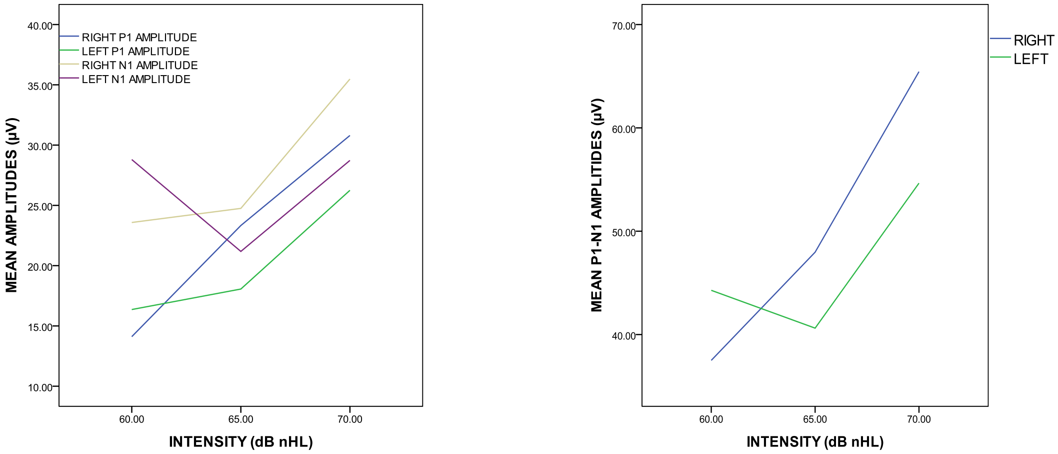


Figure 4.8. Effect of intensity on mean unrectified P1and N1 latencies – BC mode.

Table 4.8 depicts the effect of intensity on mean P1 and N1 amplitudes. It can be seen from the table that amplitudes of both P1 and N1 increase with increase in stimulus levels. This effect is seen to be more consistent at the higher stimulation levels than the lower levels for both P1 and N1 amplitudes. The same can be seen from the figure 4.9 (a). Figure 4.9 (b) depicts the effect of intensity on mean P1-N1 amplitudes. P1-N1 amplitudes tended to increase with increasing stimulus levels, however, this effect was not consistent at the lower levels. A comparison between the unrectified and rectified methods revealed higher values for the unrectified method.



(a) (b)

Figure 4.9. Effect of intensity on mean unrectified amplitudes – BC mode. (a) Effect of intensity on P1 and N1 amplitudes; figure 4.9 (b) Effect of intensity on P1-N1 amplitudes.

Table 4.8.

Mean and SD of P1, N1 and P1-N1 amplitudes at different intensities for right and left ear – unrectified BC condition.

	Right						Left					
	P1		N1		P1-N1		P1		N1		P1-N1	
Intensity (dB nHL)	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
70	30.80	24.28	35.48	30.24	65.44	51.30	26.25	20.48	28.73	22.62	54.65	41.08
65	23.33	16.10	24.75	15.75	47.97	29.49	18.06	9.98	21.18	17.87	40.62	22.96
60	14.11	2.71	23.58	5.19	37.50	6.11	16.36	5.80	28.80	12.39	44.28	6.01

Thresholds

VEMP thresholds were measured using rectified and unrectified methods in AC- and BC- mode for both right and left ears. Table 4.9 depicts the mean thresholds for each of the conditions. It can be seen from the table that the mean thresholds for both the rectified and unrectified methods are comparable for the same mode of stimulation in both ears.

Table 4.9:

Mean thresholds for different VEMP recording conditions

	Rectified		Unrectified	
	Mean	SD	Mean	SD
AC	76.16	4.14	76.66	4.34
BC	66.39	4.12	66.86	3.34

Note: AC – Air conduction; BC – Bone conduction; SD – Standard Deviation.

Reliability of VEMP

a. Reliability of VEMP parameters at maximum intensity

In order to evaluate the reliability of VEMP, the VEMP recordings were done in both the rectified and the unrectified conditions for both the ears (ipsilaterally) and using both AC- (at 95 dB nHL) and BC- (at 70 dB nHL) stimuli. The reliability was evaluated using the Cronbach's Alpha test and α values greater than 0.7 were considered to have excellent reliability, lesser than 0.4 were considered to have poor reliability and the intermediate values were considered to have fair/moderate reliability. This scale of categorization is based on the scale used by Versino, Colnaghi and Callieco (2001).

Table 4.10 shows the reliability values of the different VEMP parameters for the rectified and unrectified conditions viz, P1 and N1 latency, inter-peak latency differences and the interaural latency differences. It can be observed from the table that the reliability of the latencies varied from poor to moderate with only interaural latency differences for P1 showing poor reliability in the rectified condition. Apart from this, all the other parameters were moderately reliable for both the rectified and unrectified conditions. A comparison between the rectified and unrectified conditions showed slightly better reliability values for the unrectified condition with the exception of P1 latency, which showed marginally better reliability for the rectified condition.

Table 4.10:

Reliability of VEMP latency parameters in the AC-mode – comparison across rectified and unrectified conditions.

	Rectified		Unrectified	
Parameter	α	Degree	α	Degree
P1 latency	0.57	F/M	0.41	F/M
N1 latency	0.46	F/M	0.48	F/M
Interpeak latencies	0.52	F/M	0.61	F/M
Interaural latencies (P1)	0.39	P	0.42	F/M
Interaural latencies (N1)	0.43	F/M	0.49	F/M

Note: F/M – Fair/Moderate; P - Poor

The amplitude parameters were also tested for reliability for both the rectified and unrectified conditions. Table 4.11 shows the reliability values for the different amplitude parameters of VEMP in both the conditions. An overall trend of moderate to excellent reliability was observed for the different amplitude parameters. A comparison between the rectified and the unrectified counterparts portrays a similar picture to the latency parameters, with the unrectified coming out trumps in this comparison as well. The only exceptional case was the P1-N1 amplitude where the two conditions were equally reliable.

Table 4.11:

Reliability of VEMP amplitude parameters in the AC-mode – comparison across rectified and unrectified conditions.

	Rectified		Unrectified	
Parameter	α	Degree	α	Degree
P1 amplitude	0.66	F/M	0.73	E
N1 amplitude	0.65	F/M	0.82	E
P1-N1 amplitude	0.66	F/M	0.66	F/M
Asymmetry ratio	0.49	F/M	0.65	F/M

Note: F/M – Fair/Moderate; E – Excellent.

The reliability values and the comparison of rectified and unrectified conditions for the latency parameters are shows in table 4.12. The α values ranged between poor and moderate for the different latency parameters of BC- VEMP. Also, the two conditions of recording demonstrated comparable results except for P1 latency and inter-peak latency differences. The rectified condition revealed higher reliability values for the P1 latency in contrast to the inter-peak latency difference where the unrectified procedure produced better results.

Table 4.12:

Reliability of VEMP latency parameters in the BC-mode – comparison across rectified and unrectified conditions.

	Rectified		Unrectified	
Parameter	α	Degree	α	Degree
P1 latency	0.44	F/M	0.39	P
N1 latency	0.48	F/M	0.41	F/M
Interpeak latencies	0.38	P	0.44	F/M
Interaural latencies (P1)	0.42	F/M	0.41	F/M
Interaural latencies (N1)	0.42	F/M	0.44	F/M

Note: F/M – Fair/Moderate; P – Poor.

Table 4.13 describes the reliability values for the different amplitude measures of BC- VEMP for both the rectified and unrectified methods. It can be seen from the table that amplitude parameters were moderately reliable for BC- VEMPs except for the asymmetry ratios in the rectified condition which showed poor test-retest reliability.

Comparison of the rectified and unrectified conditions revealed better α values for the rectified conditions, asymmetry ratio notwithstanding. The asymmetry ratios were comparable for the two methods.

Table 4.13:

Reliability of VEMP amplitude parameters in the BC-mode – comparison across rectified and unrectified conditions

	Rectified		Unrectified	
Parameter	α	Degree	α	Degree
P1 amplitude	0.48	F/M	0.42	F/M
N1 amplitude	0.42	F/M	0.40	F/M
P1-N1 amplitude	0.54	F/M	0.50	F/M
Asymmetry ratio	0.39	P	0.38	F/M

Note: F/M – Fair/Moderate; P – Poor.

a. Reliability of VEMP parameters at threshold

Threshold of VEMP is defined as the minimum level of the stimulus at which a VEMP response could be reproducibly observed. The VEMP thresholds were measured in both the rectified and unrectified conditions, using AC- and BC- modes. The reliability of VEMP parameters at threshold level was evaluated using the Cronbach's alpha and the same scale was used to categorise the degree of reliability for both the conditions. Table 4.14 shows the AC- and BC- VEMP reliability comparison for the rectified and unrectified methods of recording.

Table 4.14:

Reliability of thresholds of VEMP.

	Air-conduction		Bone-conduction	
	α	Degree	α	Degree
Rectified	0.69	F/M	0.41	F/M
Unrectified	0.71	E	0.51	F/M

Note: F/M – Fair/Moderate; E – Excellent

It can be seen from table 4.14 that the reliability of AC- threshold for the rectified method was higher than the reliability of the rectified method. It can also be observed from table 4.14 that the reliability of BC thresholds was moderate for both methods, with the unrectified method showing slightly higher α values.

The test-retest reliability was also evaluated at the thresholds of each of the individuals in both the conditions for AC- as well as BC- mode of stimulation. Tables 4.15 and 4.16 depict the reliability values of the different VEMP parameters at the threshold for AC- and BC- modes respectively. The parameters evaluated for the reliability at threshold were P1 latency, P1 amplitude, N1 latency, N1 amplitude and P1 – N1 amplitude difference. The Cronbach’s alpha test was used to evaluate the reliability and the scale given by Versino et al. (2001) was used for the categorization of the degree of reliability.

It can be seen from table 4.15 that the reliability of P1 latency and N1 amplitude at the thresholds in the AC mode was found to be moderate for both the rectified and unrectified methods. The reliability values for the other three parameters (P1 amplitude, N1 latency & P1-N1 amplitude) were poor for the rectified and the unrectified methods. A comparison of the two methods revealed results that tilted in favour of the rectified method with the expection of P1 latency where the unrectified method observed higher α values. Overall though, the reliability of the different parameters was grossly poor.

Table 4.15:

Reliability of VEMP parameters at thresholds – AC mode.

	P1				N1			
	Latency		Amplitude		Latency		Amplitude	
	α	Degree	α	Degree	α	Degree	α	Degree
Rectified	0.44	F/M	0.26	P	0.25	P	0.56	F/M
Unrectified	0.55	F/M	0.09	P	0.16	P	0.45	F/M

Note: F/M – Fair/Moderate; P – Poor

Table 4.16:

Reliability of VEMP parameters at thresholds – BC mode.

	P1				N1			
	Latency		Amplitude		Latency		Amplitude	
	α	Degree	α	Degree	α	Degree	α	Degree
Rectified	0.43	F/M	0.36	P	0.38	P	0.34	P
Unrectified	0.41	F/M	0.29	P	0.43	F/M	0.36	P

Note: F/M – Fair/Moderate; P - Poor

Comparing the AC- and BC- VEMP reliability revealed a clear trend towards better reliability values for the AC- VEMP parameters at thresholds, P1 latency notwithstanding. For the P1 latency alone, the BC- VEMP showed marginally higher reliability values. The reliability of the P1-N1 amplitudes for both the AC- and BC- VEMPs were moderate for both rectified and unrectified methods.

In summary, statistical analysis of the data revealed that there was a clear effect of intensity on the different VEMP parameters for both the rectified and unrectified methods using AC- and BC- modes of stimulation. The amplitudes showed an increasing trend for increasing intensity levels. This effect was not consistent for the latencies and was found to have no statistically significant differences. The Cronbach's alpha test showed that the test-retest reliability of VEMP varies from moderate to excellent for the AC- VEMP and poor to moderate for the BC- VEMP (in both rectified & unrectified conditions), with the amplitude measures generally having better reliability values than the latency measures. The reliability of the AC- VEMPs was found to be higher than that of BC- VEMP in both the rectified and unrectified conditions for nearly all the parameters considered.

CHAPTER-5

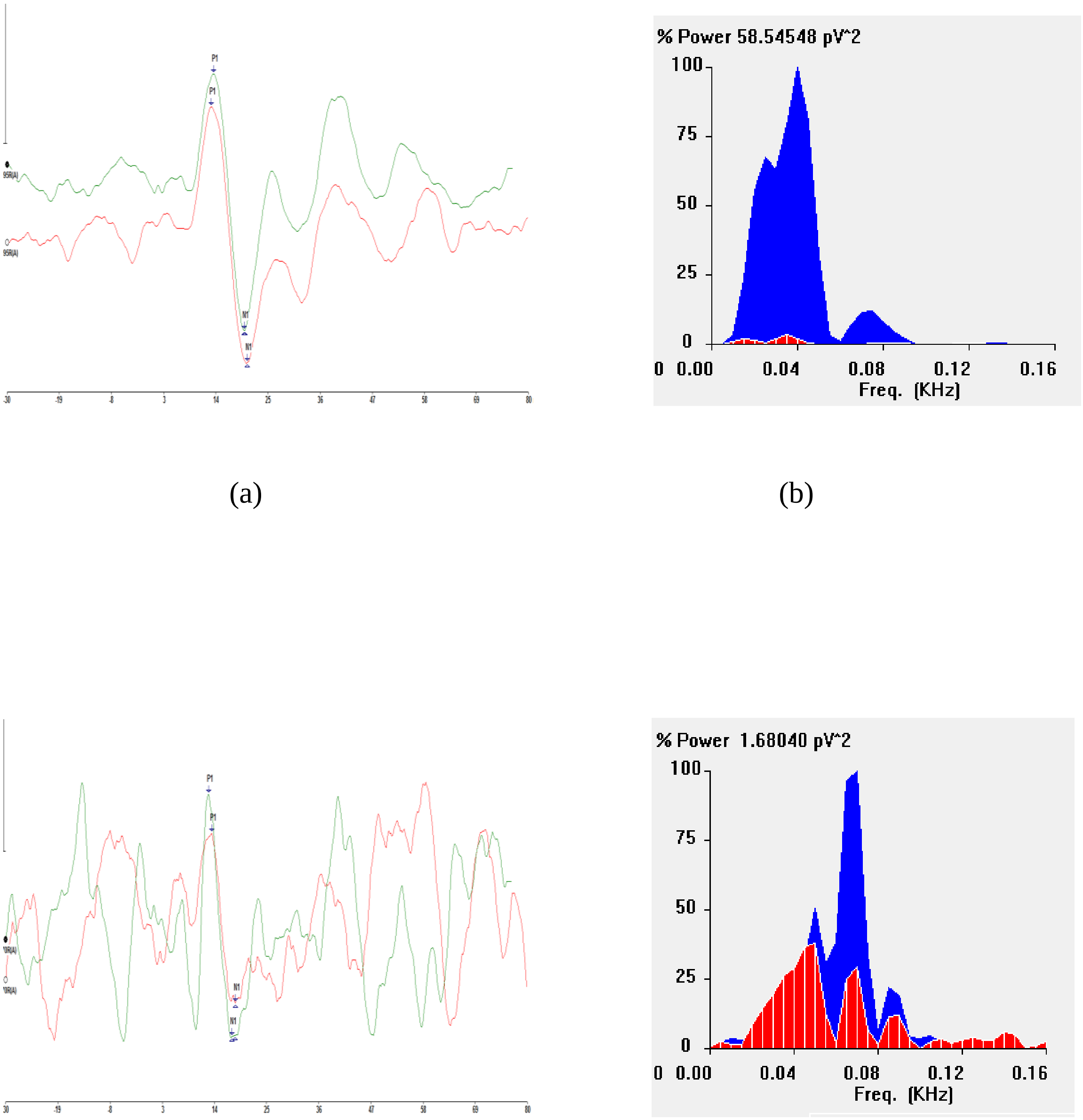
DISCUSSION

The results of the current study indicated towards clear trends of affect of stimulus level on different VEMP parameters, especially amplitudes across the different modes of stimulation and the different methods of recording. The reliability values were also measured for each of the parameters at the highest intensity and at the threshold for both the conditions.

Effect of stimulus level on VEMP parameters

Most previous researches, on the effect stimulus level on the latencies, have indicated that the latencies do not change with change in stimulus levels. Akin and associates (2003) reported unchanged VEMP latencies with variations in click levels over a range from 90- to 100- dB nHL. Ochi et al (2001) also reported relative stability of VEMP latencies (P1 and N1) over a range of click levels from 95- to 105 dB nHL. However in the present study, the latency parameters indicated a general trend towards increase in the latencies of P1 and N1 peaks with increase in the stimulus levels. The effect was more evident for the N1 latencies than the P1 latencies. However, a paired t-test revealed the changes to be statistically insignificant.

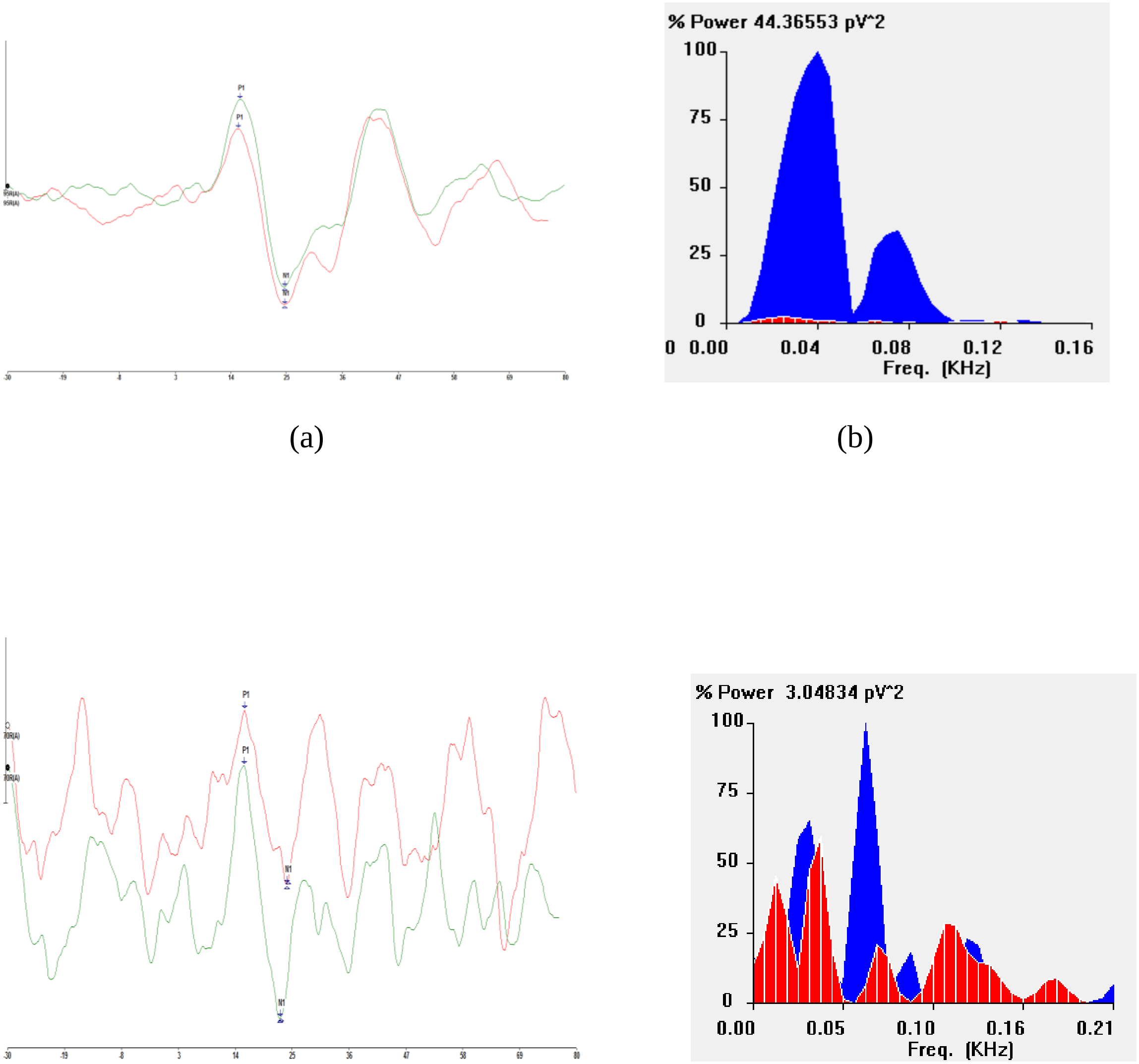
A possible explanation to changes in latencies could be the change in the response spectrum with reduction in stimulus levels. Figures 5.1 (a) and (b) show the waveforms of one of the subjects at 95 dB nHL and the corresponding power spectrum of the response respectively. Figures 5.1 (c) and (d) also show the same for a 70 dB nHL response. It can be clearly seen from the figures that there is a change in the spectral composition of the response for the 95 dB and 70 dB nHL stimuli. The response spectrum for the highest intensity can be seen to be dominated by a large low frequency response (at approximately 40Hz) whereas at the lowest intensity, the low frequency dominance does not exist, instead the most dominant frequency is shifted to a higher frequency value (to approximately 80 Hz) for the low intensity response. The effect of such a change in the spectral domain also changes the temporal domain of the response. The finding of a broad response waveform for the highest intensity (because of a low- frequency dominance) changes to a much sharper response waveform at the lowest intensity which indicates towards a change in response frequency towards the higher frequencies value. Although this effect is not clearly evident for the P1 peak from the above example, the effect is still the same, thus changing the response latencies of both the peaks. Figures 5.2 (a) to (d) also depict the same changes in the spectral and waveform characteristics in the same participant when measured using the unrectified method. Similarly, the spectral and temporal waveform at the highest intensity and threshold for BC- stimulation in the same participant is shown in figure 5.3 (a) to (d).



(a) (b)

(c) (d)

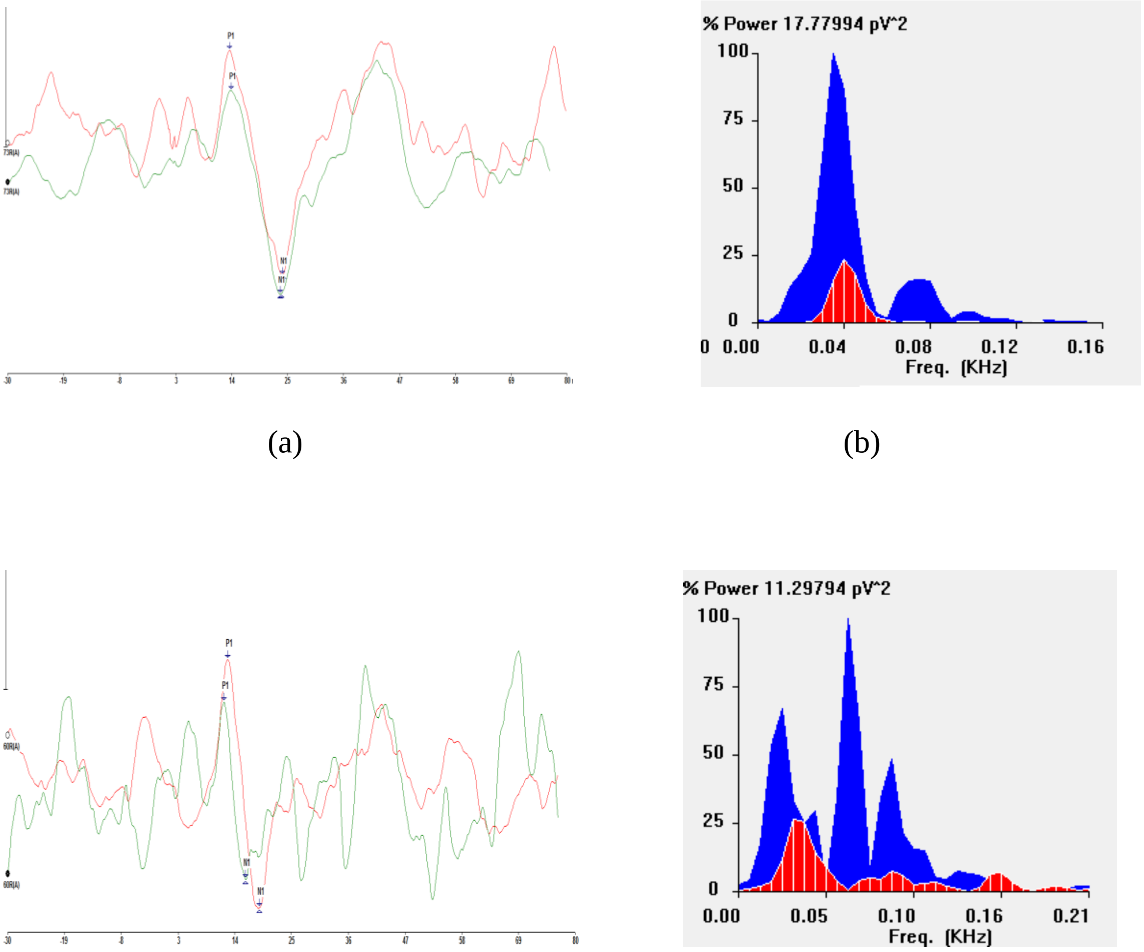
Figure 5.1. Response power spectrum and waveforms recorded from one of the participants at highest intensity and threshold using the rectified method for AC-stimulation.



(a) (b)

(c) (d)

Figure 5.2. Response power spectrum and waveforms recorded from one of the participants at highest intensity and threshold using the unrectified method for AC-stimulation.



(a) (b)

(c) (d)

Figure 5.3. Response power spectrum and waveforms recorded from one of the participants at highest intensity and threshold for BC stimulation.

The effect of stimulus intensity on the amplitude measures of VEMP has been extensively studied by many researchers. Ochi et al. (2001) reported an increase in VEMP amplitudes from stimulus levels of 85 dB nHL to 105 dB nHL. Results obtained by Akin et al (2003) also revealed the same trend. The results of the present study are in agreement with the available reports in literature.

The present study attempted to compare the two methods of recording for the amplitude parameters. Both the methods revealed similar trends, however, the unrectified method produced steeper slopes of the intensity-amplitude function. Lee, Kim, Son, Lim, Bang and Kang (2008) reported that the mean amplitudes and the mean inter-aural difference ratio were significantly smaller for the rectified method compared to the unrectified one. The inference of this study, in essence, shows an agreement with the findings of the present study. The possible explanation for this difference might be the amount of tension maintained in the SCM muscle for both the conditions. For the rectified condition the tension in the SCM muscle was maintained between 100 to 200% of the original muscle tension which corresponded to a range of 50 to 200 µV. Although there was no specific objective measure to assess the amount of muscle tension (in µV) for the unrectified method, it was generally reported by the participants that they needed to strain more for the unrectified method in order to reach the specific reference point on the apparatus. This could implicate in maintenance of higher amount of muscle tension. It is now an established fact that the amplitude of VEMP is directly related to the amount of muscle tension in the SCM (Versino et al, 2001; Ochi et al, 2001). Since, the SCM tension was generally greater for the unrectified method, it would be logical to expect greater amplitudes for the unrectified method in comparison with the rectified method. This also throws light on the necessity to obtain separate norms for the two methods.

The VEMP thresholds were measured in the AC- and BC- mode for both the rectified and unrectified methods. For the AC mode, the mean thresholds were found to be comparable for the rectified and unrectified methods. The mean thresholds in AC-mode was 76.16 (SD ±4.14) for the rectified method and 76.66 (SD ±4.34) for the unrectified method. These values of thresholds are better than those reported in literature to be 80- to 95 dB nHL (Colebatch et al, 1994). In later studies by Colebatch et al (1998), the authors report that thresholds for AC- clicks to range between 70 dB nHL and 86 dB nHL and also indicated that thresholds lower than 70 dB nHL indicated hypersensitivity of the vestibular system (Tullio phenomenon). None of the participants of the current study fitted the Colebatch et al (1998) criteria of hypersensitivity. A possible reason for the better thresholds in the present study could be the use of a tone burst to elicit VEMP rather clicks used in the previously mentioned studies. Akin et al (2003) reported that tone-bursts required lower levels of stimulation compared to clicks to elicit a VEMP response, which is in agreement with the present study.

Test-retest reliability of VEMP parameters

The test-retest reliability was established at both highest intensity level as well as the thresholds for the rectified and unrectified methods using AC- and BC- stimulation. Statistical analysis using the Cronbach's alpha test indicated that the amplitude measures were generally more reliable than the latency measures.

In the AC- stimulation, it was seen that the unrectified method was more reliable for the inter-peak latency difference, P1 amplitude, N1 amplitude, and the asymmetry ratio than the rectified method. For the other parameters like the N1 latency, inter-aural latencies (of both P1 & N1) and the P1-N1 amplitude, the reliability was found to be comparable between the two modes. This indicates that the general reliability of the unrectified method is better than the rectified method for AC- stimulation. Isaradisaikul et al (2008) also found similar results and reported the unrectified method to be more reliable than the rectified method, especially for the P1 latency, N1 latency and P1-N1 amplitude. For the other parameters, they found the reliability to be comparable across the two methods. Though the devices used for the rectified and unrectified methods in the various studies (Nguyen et al, 2010; Maes et al, 2009; Vanspauwen et al, 2009) were different, the final outcomes were consistent with the present study. Bickford et al. (1964) reported that the VEMP responses were detected better with the unrectified method compared to the rectified method.

A possible reason for the better reliability of the unrectified method could be the use of a specific point target which was required to be achieved in order to record VEMP. This may yield nearly the same amount of tension for the test and the retest conditions and hence result in better reliability. However, a range target (50μV to 200μV) was used to consider the appropriate muscle tension on the SCM for the unrectified method. This could result in maintenance of unequal tension, though still within the acceptable range, and thereby result in relatively poorer reliability. This also means that the unrectified method (using the apparatus in the present study) can be used with equal confidence, if not more, to that of the rectified method.

The reliability of BC- VEMPs was also measured for the rectified and unrectified conditions at 70 dB nHL. Results indicate that the reliability varied from poor to moderate for the different VEMP parameters. The latency and amplitude measures showed similar reliability values for the rectified and unrectified methods. A comparison of the reliability of the AC and BC VEMP parameters revealed higher α values for the AC, indicating higher test-retest reliability for the former. There are a number of reasons that could alone or in conjunction explain the occurrence of such a finding.

1. Placement of BC: In the present study, BC- VEMP was recorded by placing the bone vibrator on the mastoid. Welgampola et al (2003) reported that VEMP responses to bone conduction stimulation occurred more consistently when recorded from mastoid stimulation than other bone vibrator placements like the frontal, occipital, or anterior temporal sites (stimulus applied anterior to the external auditory canal). They also reported that the largest BC- VEMPs were elicited when the bone vibrator was placed 3 cm posterior and 2 cm superior to the external auditory canal. Although the bone vibrator was placed on the mastoid in the present study, the exact location on the mastoid (as given by Welgampola et al, 2003) was not considered. This might have lead to reduced VEMP amplitude, leading to a reduced SNR. However, it needs to be further explored by maintaining same placement and evaluating the reliability of BC- VEMP.
2. Post Auricular Muscle Response: Another source of contamination might be the presence of post-auricular muscle response, which shares the same latency, amplitude and spectral characteristics with VEMP.

3. Amplitudes of BC- VEMP: The amplitudes of BC- VEMP are generally lower than that of AC VEMPs. When the amplitudes are lower, there is higher possibility of other muscle potentials masking or altering the VEMP responses by increasing the noise floor of the recording. This effectively makes it similar to recording VEMPs at levels which are closer to the threshold level. It can be seen in the results that the reliability values of VEMP are generally poorer at or near to thresholds compared to higher stimulation levels (refer figure 5.3 a to d).

4. Frequency of the tone burst: VEMP responses exhibit a frequency tuning characteristic. Welgampola et al (2003) reported the best responses were obtained for 200 to 250 Hz stimuli. In the present study, a 500 HZ tone bursts was used to elicit BC-VEMPs which might have led to lesser reliability. However, the reliability of VEMP using the 250 Hz tone burst needs to be explored to establish the above mentioned reason for the poorer reliability values obtained in the study.

5. Distortions: A bone vibrator adds significant amount of distortions to the stimulus at such high levels as used in the present study. These distortions might be spectral as well as temporal which in turn might affect the recording of BC- VEMP.

6. Stimulus artifacts: Another source of contamination might be stimulus artifacts which might hamper the recording to a certain extent.

Test-retest reliability of thresholds

A comparison of reliability of thresholds for both the methods yielded comparable results with the reliability being excellent for both. Isaradisaikul et al (2008) found that the thresholds measured using the rectified and the unrectified methods were similar to each other, with the reliability values being moderate for both. One possible reason for the poorer reliability (in comparison to the present study) of thresholds in the study by Isaradisaikul et al (2008) might be the significantly lower number of participants (20) considered in their study as compared to the 75 in the present study.

The results of comparison between rectified and unrectified methods for BC-VEMP also yielded comparable α values. However, these values were lower and fell under the moderate category as opposed to the excellent category for AC. The possible reason for a reduced reliability of BC- VEMP threshold might be the poor SNR of the responses because of relatively smaller amplitudes for BC- VEMP.

Reliability of VEMP parameters at threshold

Results indicate that the reliability of VEMP parameters at thresholds is much lower than the reliability measured at the highest intensity. This trend is most evident for the AC- VEMP where the reliability decreases from near excellent values to moderate or even poor for many parameters. For the BC- mode, the reliability values at threshold also reduced compared to the reliability at highest intensity. This might also be attributed to the lower amplitudes resulting in reduced signal to noise ratios. This would result in poorer morphology of the acquired waveforms and make the peak marking task more difficult. Similar reason was suggested for AC- VEMP in a study by Bickford (1972). This may also be applicable to BC as the worsening of SNR appears to be a lot more for BC at the threshold compared to the AC counterpart (as explained earlier).

CHAPTER-6

SUMMARY AND CONCLUSIONS

Vestibular Evoked Myogenic Potential is an inhibitory muscle potential recorded from the sterno-cleido-mastoid muscle in response to an intense acoustic stimulus. VEMP is a component of the Vestibulo-Collic reflex pathway which helps to maintain the position and orientation of the head on the shoulders when there is a stimulation of the vestibular system (in response to the intense sound). The VEMP responses help to assess the functioning of the saccule and the inferior vestibular nerve which form an integral part of the vestibulo-collic pathway.

The clinical use of VEMP is a more recent entity and generally limited to the use of peak-to-peak amplitude (P1-N1) and asymmetry ratio. However, there are variable reports in literature regarding the test-retest reliability of these parameters with the reports varying from poor reliability (Isaradisaikul et al, 2008) to moderate to excellent reliability (Maes et al. 2009; Vanspauwen et al. 2009). A clinical tool must be sufficiently reliable and the reliability of all the parameters must be explored to enable better clinical usage of the test. Hence, the present study was aimed at evaluating the effect of stimulus intensity on the different VEMP parameters and also finding the test-retest reliability of VEMP parameters using the rectified and unrectified methods, for the AC- and BC-stimulation.

In the present study, VEMP recordings were done on 80 subjects using both the rectified and unrectified methods, for AC- and BC- stimulation at the highest intensity, at the threshold and at 5 dB intervals in between the two. For the rectified method, the amount of muscle tension on the SCM muscle was considered appropriate when the muscle tension was maintained between 50 and 200 µV. For the unrectified method, the tension on the SCM was considered appropriate when the subject touched the lateral side of his chin to the reference point of a specially fabricated device.

The data obtained was statistically analysed and the results indicated varying trends for the effect of stimulus intensity on the different VEMP parameters. The latency measures revealed an increasing trend with increasing stimulus levels (not statistically significant), whereas the amplitude measures showed a near-linear increase in their values as the intensities were increased. The trends were consistent for both rectified and unrectified methods and using AC- and BC- stimulation, although the BC- VEMP parameters showed slightly greater variability. All the results are consistent with reports in literature (Ochi et al., 2001; Akin et al., 2003 & others).

The test-retest reliability was also evaluated for the different VEMP parameters using the rectified and unrectified procedures for AC and BC stimulation. Results indicated that the reliability of the unrectified method was comparatively higher than the rectified method for most of the parameters of AC- VEMP. This may be attributed to a greater amplitude (hence a better SNR) and more consistent maintenance of tension on the SCM for the unrectified method in comparison to the rectified method. For the BC- VEMP parameters, the reliability values were comparable for both the rectified and unrectified methods. Comparison of the two modes (AC & BC) revealed lesser reliability for the BC- VEMP. This may be explained on the basis of a reduced amplitude and SNR for BC- VEMP and the possible contamination of BC- VEMPs by many sources (mentioned in detail in the discussion). The test-retest reliability of VEMP thresholds revealed comparable results for rectified and unrectified methods (both excellent) whereas the BC-VEMPs were moderately reliable for both the methods. This may be attributed to the above mentioned reasons. Unlike the threshold itself, the different VEMP parameters at threshold revealed poor to moderate reliability.

Thus it can be finally concluded that

- Reliability of VEMP ranged between moderate and excellent, barring few exceptions.
- Unrectified condition of recording VEMP produced higher reliability values than rectified counerparts, few exceptions notwithstanding.
- AC- VEMP was more reliable than BC- VEMP.
- The amplitude parameters were found to be more reliable than latency counterparts.
- Reliability of VEMP thresholds was found to be excellent.
- Reliability of the different VEMP parameters was significantly higher at maximum intensities compared to the threshold level.

Implications of the study

- The results of the present support the use of unrectified VEMP with equal confidence to that of the rectified method.

- The apparatus used in the study can be easily fabricated and prove to be a cost-effective substitute for the expensive instruments for rectified method.
- Unlike the reports in literature, the present study found moderate to excellent reliability for most of the VEMP parameters. This would implicate in clinical use of VEMP with confidence

Future directions

- The results showed that there is a significant change in the response spectrum with changes in stimulus levels, possibly leading to changes in the latencies of the VEMP responses. This finding needs further research to establish if the changes in the spectral characteristics of the response actually change the latencies.
- The reliability of BC- VEMP needs to be further explored, keeping in mind the tuning characteristics of VEMP and also the most appropriate position of the bone vibrator on the mastoid needs to be established.
- Objective methods of peak marking, especially at or near threshold levels, can be researched upon considering the spectral characteristics and the effective signal to noise ratios of the response.

CHAPTER-7

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