# Test-Retest Reliability of Vestibular Evoked Myogenic Potentials Parameters

[1]Anoop B. J. & [2]Niraj Kumar Singh


## Abstract

*Vestibular evoked myogenic potentials (VEMPs) have been used to evaluate the functioning of the saccule and inferior vestibular nerve. However there are discrepancies in literature regarding the test-retest reliability of VEMPs. Hence the present study aimed at evaluating the test-retest reliability of VEMP parameters. In the present study, VEMPs were measured in 80 subjects with normal audio-vestibular system using AC- and BC-stimulation under rectified and unrectified conditions. The rectified VEMPs were recorded by using a visual monitoring device and the unrectified VEMPs were recorded by using a specially fabricated device at maximum intensities and threshold. Descriptive statistics was done to see the effects of stimulus level on VEMP parameters and Cronbach's Alpha test was done to measure the test-retest reliability of VEMP. Results revealed an increasing trend for amplitudes with increase in stimulus levels in all conditions. Latency measures also showed a tendency to increase with intensity but were not statistically significant. The test-retest reliability of amplitudes was higher than the latency measures, AC was more reliable than BC, unrectified method had higher reliability than rectified, VEMP thresholds had comparable reliability across all conditions and the reliability of VEMP parameters at thresholds were generally poor.*


***Key words:*** *Rectified VEMP, unrectified VEMP, sterno-cleido-mastoid muscle.*

## 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, VEMP testing has been used as a clinical test of vestibular, more specifically, saccular function.

Sound-evoked vestibular responses in humans were described by 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. Vestibular-dependent short-latency lectromyographic (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. 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.

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, Vanspauwen, Wuyts and Van de Heyning (2009) 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

[1]Email: anoop2187@gmail.com; [2]Lecturer in Audiology, Email: niraj6@gmail.com

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 (Akin & Murnane, 2001). 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, 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.

Hence 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.

## Method

Eighty individuals with normal audio-vestibular system in the age range of 18 to 40 years (mean age=26.7 years) served as the participants of the study. 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 and Grason Stadler Inc. – Tympstar clinical immittance meter were used for routine audiological evaluation. Intelligent Hearing Systems Smart EP version 4.0 evoked potentials system with ER-3A insert earphones and Radio ear B-71 bone vibrator were used for the recording of air- and bone- conducted VEMP responses respectively. VEMPs 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 Unrectified and Rectified conditions. The tension of the SCM muscle during the unrectified procedure was considered appropriate when the subject touched the board of a specially fabricated device with the lateral side of his/her chin while turning his/her head as shown in Figure 1 (a). The SCM muscle tension was monitored using an inbuilt visual feedback system for the rectified procedure as shown in Figure 1 (b).

Each subject was tested on two different days within a week of each other using the protocols mentioned in Table 1 for AC- and BC- VEMP. 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 two recordings. The recordings were randomized with respect to the intensity, transducer, ear and the procedure used. The parameters measured included, absolute amplitudes of P1 and N1, peak to peak amplitude of the P1-N1 complex, absolute latencies of P1 and N1, P1-N1 inter-peak latency difference, latency-intensity function, amplitude-intensity function, inter-aural latency and amplitude differences and symmetry ratio using the formula [AR=100|(AL–AR)/AL+AR)|] (Colebatch, Day, Bronstein, Davies, Gresty, Luxon, & Rothwell). 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.


*Figure 1: Recording of (a) unrectified VEMP using the specially fabricated apparatus and (b) rectified VEMP using the visual feed-back mechanism from one of the participants (Photographs were obtained with informed consent of the participant).*

*Table 1: Recording protocol for VEMP*

| Stimulus parameters | |
|---|---|
| Stimulus frequency | 500 Hz tone burst |
| Stimulus duration | 2-1-2 cycle (equivalent to 10ms total duration) |
| Stimulus intensity | 95 dBnHL (for AC- stimulation) or 70 dB nHL (for BC- stimulation) or variable intensities (5 dB step size) |
| Transducer | ER-3A Insert earphones (300Ω) and B-71 bone vibrator |
| Repetition rate | 5.1/s |
| Number of sweeps | 150 |
| Polarity | Alternating |
| Acquisition parameters | |
| Electrode montage | *Non-inverting*: 2/3$^{rd}$ of the distance of the insertion of the Sterno-cleido-mastiod muscle, on the ipsilateral side of the test ear<br>*Inverting electrode*: Sterno-clavicular junction<br>*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 |

## 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. Descriptive statistics (mean & standard deviation) was done for different VEMP parameters to see the effect of stimulus intensity on VEMP parameters and 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.

**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.

*Air Conduction VEMP:* Figure 2(a) depicts the effect of stimulus intensity on the P1 and N1 latencies recorded using the rectified and unrectified mode for AC- stimulation. A general trend towards increase in latencies of P1 and N1 with increase in stimulus level was observed. The statistical analysis using the paired t-test yielded no statistically significant difference ($p>0.05$). This trend was consistent for both rectified and unrectified procedures. Figure 2 (b) shows the effect of stimulus on the P1, N1 and P1-N1 amplitudes for both rectified and unrectified methods using AC- stimulation. It can be seen from the figure that the amplitudes tend to increase with increasing stimulus levels for all the three peaks. The slopes of the amplitude-intenstiy functions for all peaks were steeper for the unrectified method.

BC VEMPs were recorded at different intensities for the unrectified method. The parameters measured were the same as those of rectified BC VEMP. Figure 3 (a) shows the effect of stimulus intensity on BC-VEMP latencies. The graph shows no significant changes ($p>0.05$) in the latencies of P1 and N1 peaks in any of the conditions with increase in stimulus intensity. Figure 3 (b) shows the effect of stimulus levels on VEMP amplitudes for BC- mode. Like AC-mode, BC- VEMP amplitudes also tended to increase with increase in stimulus levels and also the amplitude-intensity functions had steeper slope for the unrectified procedure.

**Thresholds**

VEMP thresholds were measured for AC- and BC-mode for both right and left ears. Table 2 depicts the mean thresholds for each of the conditions. It can be

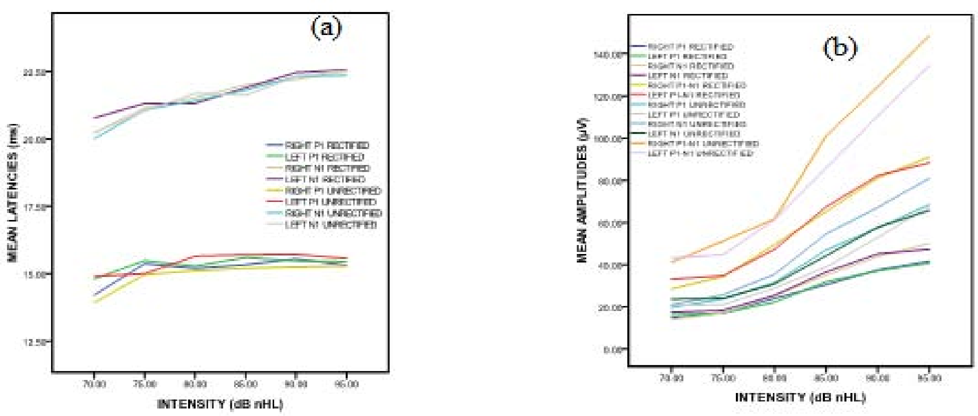



*Figure 2: Effect of stimulus intensity on (a) mean P1 and N1 latencies and (b) mean amplitudes of P1, N1 and P1-N1 peaks of right and left ears measured for both rectified and unrectified procedures when stimulated using the AC- mode.*

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.

**Reliability of VEMP**

*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 (ipsilaterally) and using both AC- (at 95 dBnHL) and BC- (at 70 dBnHL) stimuli. The reliability was evaluated using the Cronbach's Alpha test and $\alpha$ 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 was based on the scale used by Versino, Colnaghi and Callieco (2001).

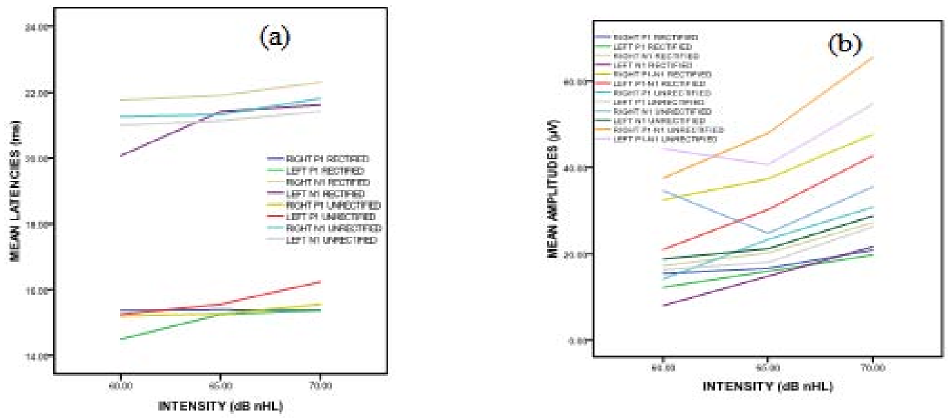



*Figure 3: Effect of stimulus intensity on (a) mean P1 and N1 latencies and (b) mean amplitudes of P1, N1 and P1-N1 peaks of right and left ears measured for both rectified and unrectified procedures when stimulated using the BC- mode.*

*Table 2: Mean and Standard Deviation (SD) of thresholds for different VEMP recording conditions*

| Mode | Rectified | | Unrectified | |
|---|---|---|---|---|
| | Mean (dBnHL) | SD | Mean (dBnHL) | S.D |
| Air Conduction | 76.16 | 4.14 | 76.66 | 4.34 |
| Bone Conduction | 66.39 | 4.12 | 66.86 | 3.34 |

Table 3 shows the reliability values of the different VEMP parameters. The reliability of the latencies varied from poor to moderate with only interaural latency differences for P1 showing poor reliability in the rectified condition. A comparison between the rectified and unrectified conditions revealed slightly higher reliability values for the unrectified condition with the exception of P1 latency, which showed marginally better reliability for the rectified condition. The reliability values ranged between moderate and excellent for the different amplitude parameters.

A comparison between the rectified and their unrectified counterparts portrayed 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 produced comparable reliability values.

The reliability values and the comparison of rectified and unrectified conditions for the latency and amplitude parameters for BC VEMPs are shown in Table 4. The α values ranged between poor and moderate for the different latency parameters. The two conditions of recording demonstrated comparable results. 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.

*Reliability of VEMP parameters at threshold:* 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 test. Table 5 shows the AC- and BC- VEMP reliability comparison for the rectified and unrectified methods of recording. It can be seen from the table that the reliability of AC- threshold for the rectified method was higher than that of the rectified method. It can also be observed from the table 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 for each of the parameters in both the conditions for AC- as well as BC- mode of stimulation. Table 6 depicts the reliability values of the different

*Table 3: Reliability of VEMP parameters in the AC-mode – comparison across rectified and unrectified conditions*

| Parameter | Amplitude | | | | Latency | | | |
|---|---|---|---|---|---|---|---|---|
| | Rectified | | Unrectified | | Rectified | | Unrectified | |
| | α | Degree | α | Degree | α | Degree | α | Degree |
| P1 | 0.66 | F/M | 0.73 | E | 0.57 | F/M | 0.41 | F/M |
| N1 | 0.65 | F/M | 0.82 | E | 0.46 | F/M | 0.48 | F/M |
| P1-N1 | 0.66 | F/M | 0.66 | F/M | 0.52 | F/M | 0.61 | F/M |
| Interaural P1 | NA | NA | NA | NA | 0.39 | P | 0.42 | F/M |
| Interaural N1 | NA | NA | NA | NA | 0.43 | F/M | 0.49 | F/M |
| Asymmetry ratio | 0.49 | F/M | 0.65 | F/M | NA | NA | NA | NA |

*Note: E – Excellent; F/M – Fair/Moderate; P – Poor; NA – Not Applicable.*

*Table 4: Reliability of VEMP parameters in the AC-mode – comparison across rectified and unrectified condition*

| Parameter | Amplitude | | | | Latency | | | |
|---|---|---|---|---|---|---|---|---|
| | Rectified | | Unrectified | | Rectified | | Unrectified | |
| | α | Degree | α | Degree | α | Degree | α | Degree |
| P1 | 0.48 | F/M | 0.42 | F/M | 0.44 | F/M | 0.39 | P |
| N1 | 0.42 | F/M | 0.40 | F/M | 0.48 | F/M | 0.41 | F/M |
| P1-N1 | 0.54 | F/M | 0.50 | F/M | 0.38 | P | 0.44 | F/M |
| Interaural P1 | NA | NA | NA | NA | 0.42 | F/M | 0.41 | F/M |
| Interaural N1 | NA | NA | NA | NA | 0.42 | F/M | 0.44 | F/M |
| Asymmetry ratio | 0.39 | P | 0.38 | F/M | NA | NA | NA | NA |

*Note: E – Excellent; F/M – Fair/Moderate; P – Poor; NA – Not Applicable.*

*Table 5: Reliability of thresholds of VEMP*

| Condition | 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*

VEMP parameters at the threshold for AC- and BC-modes. The reliability of P1 latency and N1 amplitude at the thresholds was found to be moderate for both the rectified and unrectified methods in the AC mode. The reliability values for the other three parameters (P1 amplitude, N1 latency & P1-N1 amplitude) were poor. A comparison of the two methods revealed results that tilted in favour of the rectified method with the exception of P1 latency where the unrectified method observed higher α values. Comparing the AC- and BC-VEMP reliability revealed 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.

## 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 Murnane (2001) reported unchanged VEMP latencies with variations in click levels over a range from 90 to 100 dBnHL. Ochi, Ohashi, & Nishino (2001) also reported relative stability of VEMP latencies (P1 and N1) over a range of click levels from 95 to 105 dBnHL. 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

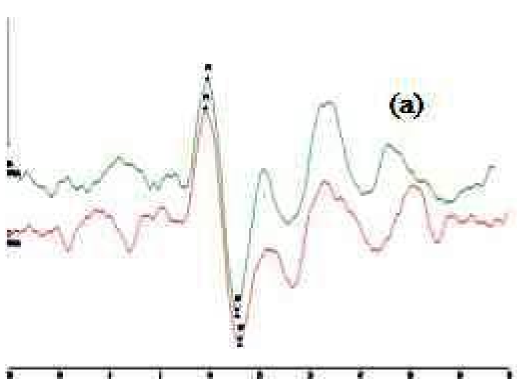
*Table 6: Reliability of VEMP parameters at thresholds*

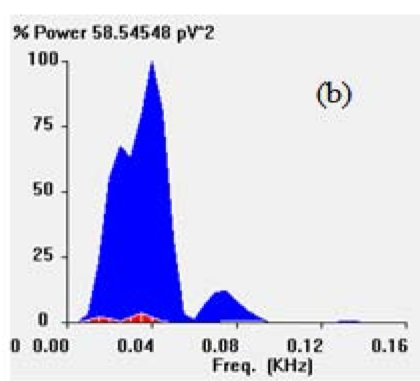
| | | P1 | | | | N1 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Latency | | Amplitude | | Latency | | Amplitude | |
| | | α | Degree | α | Degree | α | Degree | α | Degree |
| AC | Rectified | 0.44 | F/M | 0.26 | P | 0.25 | P | 0.56 | F/M |
| | Unrectified | 0.55 | F/M | 0.09 | P | 0.16 |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

possible explanation to changes in latencies could be the change in the response spectrum with reduction in stimulus levels. Figures 5 (a) and (b) show the waveforms of one of the participants at 95 dB nHL and the corresponding power spectrum of the response respectively. Figures 5 (c) and (d) also show the same for a 70 dBnHL response. It can be clearly seen from the figures that there was a change in the spectral composition of the response for the 95 dB and 70 dBnHL stimuli. The response spectrum for the highest intensity was dominated by a large low frequency response (at approximately 40 Hz) whereas at the lowest intensity, the low frequency dominance did not exist, instead the most dominant frequency 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 frequency value. Although this effect is not clearly evident for the P1 peak from the example, the effect is still the same, thus changing the response latencies of both the peaks. The same effect was evident for all conditions and modes for the study. 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 dBnHL to 105 dBnHL. Results obtained by Akin and Murnane (2001) 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



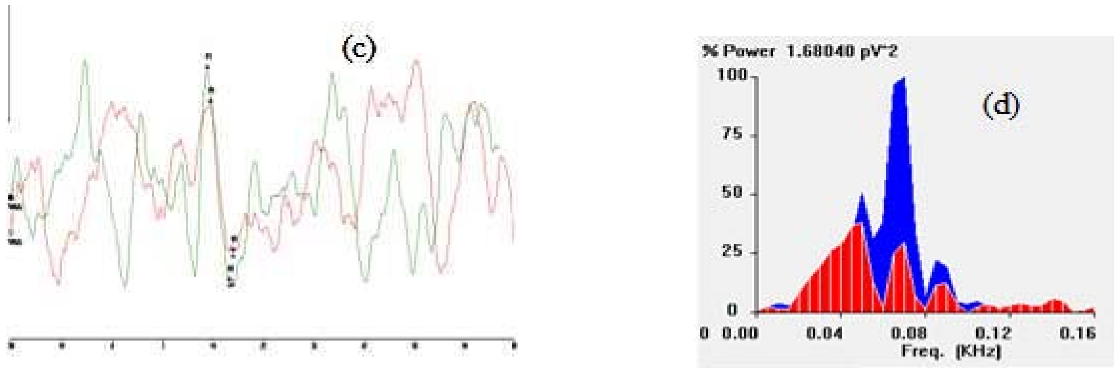



*Figure 5: Response power spectrum and waveforms recorded from one of the participants at highest intensity and threshold using the rectified method for AC- stimulation.*

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 threshold in AC- mode was 76.16 dBnHL (SD±4.14) for the rectified method and 76.66 dBnHL (SD±4.34) for the unrectified method. These values of thresholds are better than those reported in literature to be 80- to 95 dBnHL (Colebatch et al., 1994). In later studies by Colebatch et al., (1998), the authors reported the thresholds for AC- clicks to range between 70 dBnHL and 86 dBnHL and also indicated that thresholds lower than 70 dBnHL 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 and Murnane (2001) 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), 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. The present study used a specific point target which was required to be achieved in order to record unrectified 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 lower reliability values. 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 latency and amplitudes of BC-VEMPs varied from poor to moderate for different 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. In the present study, BC-VEMP was recorded by placing the bone vibrator on the mastoid. Welgampola, Rosengren, Halmagyi and Colebatch (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 accurately 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. Another source of contamination might be the presence of post-auricular muscle response, which shares the same latency, amplitude and spectral characteristics with VEMP. Third reason for such findings may be the amplitudes of BC- VEMP which were 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. Another reason could be that 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. Other reasons for these findings could be attributed to distortions produced by the bone vibrator when driven at such high levels and also the presence of stimulus artifacts.

**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 65 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 (1964). 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.

## Conclusions

The reliability of VEMP ranged between moderate and excellent, barring few exceptions. Unrectified condition of recording VEMP produced higher reliability values than rectified counterparts, 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. Hence it can be concluded that amplitude parameters should be used for diagnosis and unrectified method could be used with equal confidence, though with separate normative values.

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