Effect of tone-burst polarity on ocular vestibular evoked myogenic potential

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This Dissertation is submitted as part fulfillment
for the Degree of Master of Science in Audiology
University of Mysore, Mysore

May 2105

Dedicated

to

my Grandma

You were my greatest blessing…

Acknowledgments

First and foremost, I thank **Holy Sadguru** for giving me strength and courage to pursue all my endeavor's.

I would like to sincerely thank my guide Mr. Niraj kumar Singh, sir I thank you for your guidance and patience. You taught us the real meaning of hard work and dedication. I would truly be lost in this venture without his inspiration and constant backing. Thanks a lot sir…….

I thank my sweet family, my **papa and mummy**, for their love and care. They have been the brick wall that has supported me when I was wavering. I thank my beloved sis **Rohini**, there is no better friend than a sister, and there is no better sister than you. I thank you for your love and care towards me. I thank my younger brother **Vicky**, I am lucky to have you along with me.

I thank **Prof. S.R. Savithri**, Director of AIISH, for allowing me to present this research proposal and permitting me to conduct this study.

I thank **Dr. Ajith Kumar U, HOD, and Department of Audiology**, AIISH, for giving me permission to carry out the study in the department.

I thank **Prawin sir** for being a very approachable teacher and to all dedicated staff in the department of Audiology at AIISH; Specially **Nike sir**, **Sandeep sir, Jithin sir**, **Ganapathy sir**, **Sharath sir**, **Baba sir**, **Hemanth sir**, **Jijo sir**, **Sreeraj sir, Chandni mam**, **Geetha mam**, **Kishore sir**, and all other for being such great teachers for me….. I thank all my dear teachers at **AIISH**…

My sincere thanks to all my teachers from **Sweekar**; Specially **Swathy ma'am**, **Vani ma'am**, **Vijayalakshmi ma'am**, **Anupama ma'am**, **Shridhar si**r and all others… I learned the basics of audiology from you all…..

To my special buddy **Preetha**; for everything you did for me, you are very special to me…thank you dear!!

To my sweet friends **Machi (Sneha)**, **Priyanka**, **Vaishnavi, Vineetha and Vinodhini** for their love, care and support throughout my AIISH life.

I thank my own dudes; **Neelesh**, **Bebek**, **PG**, **Hasheem**, **Akhil**, **Thareeq**, **Himanshu**, **Jithin, Eeju**, **Suppie**, **CV**, **Guna**, **Kapali**, **Giri**, **Kiran**, **Akshay, Som, R K, Anuj**…You guys are awesome. I thank you all for the memorable moments I had with you….

I thank my sweet girlfriends of my class; **Suman, Swathy, Sowmya, Padma** for making my AIISH life memorable.

I thank **Husna** and **Aisha** for being very genuine dissertation partners.

My sincere thanks to all my juniors and seniors….

Certificate

This is certify that this dissertation entitled **“Effect of tone-burst polarity on ocular vestibular evoked myogenic potential”** is the bonafide work submitted as part fulfillment for the Degree of Master of Science in Audiology of the student with Registration No. 13AUD033. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other diploma or degree.

Mysuru, May, 2015

Prof. S. R. Savithri,
Director
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Mysore-570006.

Certificate

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

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Declaration

This dissertation entitle “**Effect of tone-burst polarity on ocular vestibular evoked myogenic potential**” 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, and has not been submitted earlier in any other University for the award of any Diploma or Degree.

Mysuru, May, 2015

Register Number: 13AUD033

Abstract

Ocular vestibular-evoked myogenic potential (oVEMP) are widely used to assess the otolith function in individuals with several vestibular pathologies. Nevertheless there is a lack of well accepted protocol for recording oVEMP. Among the several studies done for identifying the efficacy of oVEMP in clinical settings, large variability in the use of stimulus and recording parameters can be noticed. One such parameter is the stimulus polarity. Therefore the present study aimed investigating the effect of tone-burst polarity on oVEMP response parameters. In order to study the effect of stimulus polarity, oVEMP were elicited by 500 Hz tone-bursts of 125 dB peSPL for rarefaction, condensation and alternating polarities and recorded by placing the electrodes beneath the contaralateral eyes. The responses were established from 54 healthy individuals in the age range of 18-35 years. The results revealed no significant difference in the latencies, peak-to-peak amplitude of oVEMP between the tone-burst polarities ($p > 0.05$). Also there was no significant difference in signal-to-noise ratio of oVEMP waveforms between the tone-burst polarities ($p > 0.05$). Therefore oVEMP can be obtained using any of the three polarities could be used for clinical recording of oVEMP without significant alterations to response parameters.

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Chapter 1

Introduction

Vestibular evoked myogenic potentials (VEMPs) are short latency muscle potentials that are elicited in response to loud acoustic stimulation (Colebatch & Halmaygi, 1992). They can also be elicited in response to bone-conducted (Halmagyi & Colebatch, 1995) or galvanic (Welgampola & Colebatch, 2005) stimulation. These responses can be recorded from several muscles of the body which include sternocleidomastoid muscle (Colebatch, Halmagyi, & Skuse, 1994), triceps muscles (Rudisill & Hain, 2008), trapezius muscle (Ferber, Virat, Duclaux, Colleaux, & Dubreuil, 1997) and splenius capitis (Wu, Young, & Murofushi, 1999). When recorded from tonically contracted sternocleidomastoid muscle, they are called cervical VEMP (cVEMP) (Colebatch et al., 1994).

VEMP can also be recorded from the inferior extraocular muscles (beneath the eyes), using the surface electrodes placed over the inferior oblique muscle, in which case it is termed ocular VEMP (oVEMP). In contrast to cVEMP, which is an uncrossed inhibitory vestibulo-spinal response, oVEMP reflects a crossed excitatory vestibulo-ocular reflex (VOR) (Iwasaki., 2008). The VOR pathway which is responsible for producing oVEMPs is mediated by a three-neuron link that consists of the vestibular receptors, the secondary neurons in the vestibular nuclei and the ocular muscle motor-neurons (Leigh & Zee, 2006). A major pathway carrying these signals is the medial longitudinal fasciculus (Leigh & Zee, 2006).

The oVEMP waveform, when recorded from a healthy individual, is characterized by an initial negative peak at 10–12 ms (n10 or n1) and a subsequent positive peak at 15-20 ms (p15 or p1) poststimulus onset (Chihara, Iwasaki, Ushio, & Murofushi, 2007; Walther, Rogowski, Hormann, & Lohler, 2011). The largest oVEMP in response to monaural air-conduction stimuli are obtained from electrodes located just beneath the eye contralateral to the stimulus ear with the patient looking up (Todd, Rosengren, Aw, & Colebatch, 2007). The oVEMP threshold have been found to vary between 80 and 90 dB nHL in response to 500 Hz air-conduction tone-burst. (Park, Lee, Shin, Lee, & Park, 2010; Wang, Jaw, & Young 2009).

1.1 Need for study

Ocular vestibular-evoked myogenic potential are widely used to assess the otolith function in individuals with vestibular pathologies (Rosengren, Aw, Halmagyi, Todd & Colebatch, 2008; Shin, Oh, Kim, Seo, Lee, & Park, 2012; Curthoys, Vulovic and Lmanzari, 2012). Nevertheless there is a lack of well accepted protocol for recording oVEMP. Among the several studies done for identifying the efficacy of oVEMP in clinical settings, large variability in the use of stimulus and recording parameters can be noticed. One such parameter is the stimulus polarity.

Uncountable studies have been done on oVEMP. While some have used a rarefaction polarity to elicit oVEMP (Xie, Bi, & Yao, 2014; Kamali, Hajiabolhassan, Fatahi, Esfahani, Sarrafzadeh, & Faghihzadeh, 2013), some of the others have used alternating polarity (Singh & Barman 2013, 2014, Kantner & Gurkov, 2012). There are still others who have used a condensation polarity for obtaining oVEMP (Dennis, Govender, Chen, Todd, & Colebatch, 2014). The results of these studies show variability in terms of latency as well as amplitude, which might have been influenced by different stimulus polarities used in these studies. However, there is dearth of studies exploring the effect of stimulus polarity on oVEMP response parameters. Nonetheless, the effect of changes in stimulus polarity on oVEMP, close associate of oVEMP using the common otolithic origin with oVEMP, has been studied previously (Papathanassiou et al 2012). They reported no significant difference in peak-to-peak amplitude and individual peak latencies between the polarities. Further amplitude ratio between polarities.

The above study investigated the effect of stimulus polarity on cVEMP but not on oVEMP. Also they did not evaluate the effect of tone-burst polarity on signal-to-noise ratio of oVEMP as alternating polarity has been reported to eliminate some of electrical and stimulus related noises from other evoked potential recordings. Therefore there is need to investigate the effect of stimulus polarity on different parameters of oVEMP.

1.2 Aim

The aim of the study is to investigate the effect of tone-burst polarity on ocular vestibular myogenic potential.

1.3 Objectives

In order to fulfill the above mentioned aim, several specific objectives were formulated. These are mentioned below:

1. To investigate the effect of tone-burst polarity on n1 latency of oVEMP.
2. To examine the effect of tone-burst polarity on p1 latency of oVEMP.

3. To investigate the effect of tone-burst polarity on peak-to-peak amplitude of oVEMP.
4. To investigate the effect of tone-burst polarity on signal-to-noise ratio of oVEMP waveforms.

1.4 Hypothesis

The present study was taken up to test the Null hypothesis (H_0) based on the above objectives. The Null hypothesis with which the study was began are as follows

1. There is no significant difference in n1 latency of oVEMP between rarefaction, condensation and alternating polarities of tone-burst.
2. There is no significant difference in p1 latency of oVEMP between rarefaction, condensation and alternating polarities of tone-burst.
3. There is no significant difference in peak-to-peak amplitude of oVEMP between rarefaction, condensation and alternating polarities of tone-burst.
4. There is no significant difference in signal-to-noise ratio of oVEMP waveforms between rarefaction, condensation and alternating polarities of tone-burst.

Chapter 2

Literature Review

The primary function of the vestibular system is to maintain balance and gaze stability (Shumway & Woollacott, 1995). The output of the vestibular system is processed via two primary reflex pathways: the vestibulo-ocular reflex (VOR) and the vestibulo-spinal reflex (VSR). The VOR is mediated by a three-neuron link that consists of the vestibular receptors, the secondary neurons in the vestibular nuclei and the ocular muscle motor-neurons (Leigh & Zee, 2006). It is responsible for the maintenance of a stable retinal image during active head movement (Paige, Telford, Seidman, & Barnes, 1998). The VSR helps in generating compensatory body movement in order to maintain head and postural stability during movement (Mangus, 1924). The VSR comprises of two major neural tracts, the medial vestibulo-spinal tract (MVST) and the lateral vestibulo-spinal tract (LVST). The MVST helps in stabilization of head position through the innervation of the neck muscles (Wilson & Peterson, 1981) whereas LVST provides excitatory signals to the motor neurons in antigravity muscles which helps to maintain upright and balanced posture (Miselis & Richard, 2011).

There are several tests available to assess the functioning of vestibulo-spinal tract. These include Sensory organization tests of computerized dynamic Posturography and Dizziness handicapped inventory (Badaracco, Labini, Meli, Angelis, & Tufarelli, 2007). One of the tests to assess the functioning of MVST is VEMP (Colebatch et al., 1994).

Vestibular evoked myogenic potentials are short latency sonomotor responses that are elicited in response to loud acoustic stimulation (Bickford, Jacobson, & Cody, 1964; Colebatch & Halmaygi, 1992). They can also be elicited by bone-vibration (Halmagyi & Colebatch, 1995) and galvanic stimulation (Welgampola & Colebatch, 2005). Irrespective of the stimulation mode,VEMPs can be recorded from several muscles of body. When recorded from the tonically contracted sternocleidomastoid muscle, they are called cervical VEMP (Colebatch et al., 1994). cVEMPs are characterized by a positive peak occurring around 13 ms (P13). Which is followed by a negative peak occurring around 23 ms (N23) in the post-stimulus period (Colebatch & Halmagyi, 1994). They are useful in the determination of the functional integrity of the saccule and the inferior vestibular nerve (Colebatch et al., 1994).

VEMP can also be recorded from the inferior extraocular muscles using the surface electrodes placed over the skin surface overlying the inferior oblique muscle, in which case it is termed ocular VEMP (Rosengren et al., 2005). oVEMPs are produced as a crossed excitatory vestibulo-ocular reflex (Iwasaki et al, 2008) and are characterized by an initial negative peak at 10–12 ms (n10 or n1) and a subsequent positive peak at 15-20 ms (p15 or p1) post-stimulus onset (Chihara et al., 2007; Walther et al., 2011; Piker, Jacobson, Burkard, McCaslin, & Hood, 2013). The largest oVEMP response to monaural air-conduction stimuli are obtained from electrodes located just beneath the eye contralateral to the stimulus ear with patient looking upwards (Todd et al., 2007).

There are several factors which can influence the results of oVEMP. These factors can be divided majorly into subject related factors (like age, gender, body position, & gaze elevation) and stimulus related factors (such as type of stimulus, mode of stimulation, frequency, intensity, rise/fall time, & stimulus polarity). While some of these parameters are well researched and their impact on oVEMP well understood, the impact of some of the others has sparingly been investigated.

2.1 Effect of age on oVEMP

As the age increases, different sensory and motor systems of human body are found to undergo anatomical and physiological changes (Doherty, Vandervoort, Taylor, & Brown, 1993; Swash & Fox, 1972). Along with the different systems of human body, vestibular system has also been shown to develop changes with age (Colledge, Wilson, Cantley, Peaston, Brash, & Lewis, 1994; Tinetti, Williams, & Gill, 2000; Sloane, Coeytaux, Beck, & Dallara, 2001) and oVEMP is no different.

Tseng et al (2010) studied the effect of age on oVEMP in individuals in the age range of 20-79 years. The subjects were divided into 6 groups, with each age group encompassing one decade. Results revealed 100% response rate in age group of 60-69 years and 40% in age group ≥ 70 years. Also mean n1 and p1 latencies were prolonged and peak-to-peak amplitude decreased above 40 years.

Similar findings were reported by Nyugen, Welgampola, Carey, 2010) who evaluated oVEMP responses in 53 subjects in the age range of 20–70 years for 3 different stimuli (click, 500 Hz tone-burst, & 500 Hz bone-conduction stimulus). The peak-to-peak amplitude was reported to decrease after the age of 50 years. However they observed no significant difference in latency or asymmetry ratio for any of the three stimuli.

Piker, Jacobson, McCaslin, (2011) studied the normal characteristics of oVEMP in 50 individuals in the age range of 8-88 years. The 500 Hz tone- bursts were presented at 95 dB nHL for eliciting oVEMP. They reported a response rate of 100% for subjects below the age of 50 years and 77% for subjects above 55 years of age. They further reported significantly decreased amplitude of oVEMP with increasing age and concluded that greatest age effects occurred in subjects 50 years or older.

Overall, the above mentioned studies reported a significant effect of age on amplitude of oVEMP. There was decrease in the peak-to-peak amplitude with increasing age. However such differences were not observed for other parameters of oVEMP such as latency and asymmetry ratio. Also, the findings related to latencies were inconsistent with some showing prolongation of latencies with advancing age (Tseng et al., 2010) whereas oyhers observing no significant change in latencies with age (Nyugen et al., 2010).

2.2 Effect of gender on oVEMP

Gender differences in several aspects of human anatomy and physiology are well understood. Usually, men are taller and have larger set of muscles than women (Komi & Tsech, 1979). This lead the researchers to ponder if such known differences could cause perceptible changes in oVEMP. The effect of gender on oVEMP were investigated by several studies (Cheng, chen, wang, & Young 2010; Piker et al., 2011; Sung, Cheng, & Young 2011; Xie, Xu, BI, Jia, Zheng, & Zhang 2011). While majority of these studies reported larger oVEMP amplitudes in males than females and no significant differences in the latencies between the genders (Cheng et al., 2010; Sung et al., 2011; Xie et al., 2011), Piker et al (2011) observed a lack of difference in amplitude as well as the latencies of oVEMP between the genders. This indicates towards a lack of consensus among the researchers with regard to effect of gender on oVEMP, especially the peak-to-peak amplitude.

2.3 Effect of body position on oVEMP

VEMPs are responses from the otolith organs, which are highly reliant on the gravitational force and inertia for their functionality (Jacobson & Shefard, 2009). Additionally, these responses are myogenic in nature and therefore the activity of the muscles could vary with the body position. Both of these factors probably lead the researchers to assume that there could be possibility of differences in the oVEMP responses with changes in body position. Therefore effect of body position of oVEMP was investigated (Taylor et al., 2011; Wang, Hsieh, & Young, 2013),

Taylor et al (2011) studied effect of body position on 20 healthy subjects who were randomly tilted in an Eply Omniax rotator across a series of eight angles from 0° to 360° (at 45° separations) in the roll plane. Both air-conduction and bone-conduction stimulations were used separetly. They reported that head orientation had a significant effect on oVEMP reflex amplitudes for both AC and BC stimulation. For both stimuli there was a trend for lower amplitudes with increasing angular departure from the upright position. The mean amplitudes decreased by 42.6–56.8% for AC and 23.2–25.5% for BC when tilted by 180°. Significant effect of roll-plane tilt was also seen on amplitude asymmetry ratios with a trend for lower amplitudes from the dependent (down) ear. However amplitude asymmetry ratios for BC stimuli were unaffected by head and body orientation.

Wang et al (2013) studied effect of head posture on oVEMP. Twenty healthy volunteers underwent the oVEMP test via air-conduction stimulation (ACS) and bone-conduction stimulation (BCV) in 3 different positions- sitting, supine and head hanging. They reported no significant differences in terms of mean latencies, the interpeak latency intervals and asymmetry ratio, regardless of the body position. However, the peak-to-peak amplitude in the supine position was highest and it was closely followed by head hanging position. The sitting position produced lowest peak-to-peak amplitude among these body positions. All these differences were observed for bone-conduction stimulation but not for air-conduction stimulation.

Overall, the studies showed that body position had significant influence on amplitude of oVEMP. The latencies and asymmetry ratio are not altered significantly by alterations in the body position for recording oVEMP. The differences were more for BC stimulation than AC stimulation.

2.4 Effect of gaze elevation on oVEMP

Several studies explored the effect of upward gazing angle of oVEMP response parameters. While some reported changes only in amplitude of oVEMP (Iwasaki et al., 2008; Welgampola, Migliaccio, Myrie, Minor and Carey, 2009; Govender, Rosengren, & Colebatch, 2009), others studied changes in amplitude as well as latencies of oVEMP and reported a significant impact of gaze angle on amplitude but not on latency (Murmane, Akin, Kelly, & Byrd, 2011). Therefore maintaining an upward gaze angle appears to be an important aspect in recording of oVEMP; however the degree of upward gazing which should be considered optimum has not been established.

2.5 Effect of mode of stimulation in oVEMP

Otolith organs could be stimulated using different modes of stimulation such as air-conduction stimulation (Colebatch & Halmaygi, 1992), bone-conduction (Halmagyi & Colebatch, 1995) and galvanic (Welgampola & Colebatch, 2005) stimulation. The energy transmission from different modes of stimulation could be different due to the path of transmission, which may alter the oVEMP responses. This encouraged the researchers to explore the effect of mode of stimulation on oVEMP.

Todd et al (2007) obtained oVEMP in response to 500 Hz air-conduction and bone-conduction tone-bursts for 10 healthy individuals. The n1 and p1 latencies found to be 8.1-12.7 ms and 16.5-20.1 ms respectively for AC mode and 7.5-13.9 ms and 17.8-25.0 ms respectively for BC. Therefore it appears that air-conduction mode of stimulation produces earlier latencies than bon-conduction mode. Although, the galvanic mode of stimulation has been shown to be useful in obtaining oVEMP and found to be useful in the differential diagnosis between labyrinthine and retro-labyrinthine lesion (Murofushi, Monobe, Ochiai, & Ozeki, 2003), there are no studies comparing its response parameters with AC or BC mode.

2.6 Effect of type of stimulus on oVEMP

oVEMP can be elicited using different short duration stimuli like clicks and tone-bursts. These stimuli differ in terms of frequency and duration parameters which can influence the oVEMP responses. Several studies compare the oVEMP responses for the clicks against those of tone-burst (Rosengren et al., 2011; Cheng et al., 2012). They reported greater response rate and larger peak-to-peak amplitude for tone-burst evoked oVEMP than the click-evoked one, especially when the tone-burst frequency was 500 Hz.

2.7 Effect of stimulus ramping and plateau duration on oVEMP

Several studies have explored the effect of changes in rise/fall and plateau times on oVEMP. Lee et al (2008) obtained oVEMP from 13 subjects in order to study the effect of changes in rise/fall times and plateau times. The rise/fall times used were 0.5 ms, 1 ms, 2 ms and 3 ms. They concluded that the rise/fall time of 0.5 ms or 1 ms along with the plateau time of 2 ms formed the best amalgamation for clinical recording of oVEMP. However their conclusion was based on a small sample size.

Cheng, Wu, and Lee, (2012) examined effect of rise/fall time and plateau time on click and tone-burst evoked oVEMP by obtaining response from 22 healthy individual’s.

the rise-plateau-fall time combinations used were 0.5-2-0.5 ms, 0.5-4-0.5, 2-2-2 ms and 2-4-2 ms. They did not find any significant difference in latencies or amplitudes of oVEMP between these combinations of rise/fall and plateau times. Thus, there seems to be a lack of consensus regarding the affects of ramping times and plateau times on oVEMP response parameters.

2.8 Effect of repetition rate on oVEMP

Several studies explained effect of repetition rate on oVEMP (Singh, Kadisonga, & Ashitha 2014; Chang, Chen, Wang, & Young, 2010). They reported that the latencies were prolonged and amplitude was reduced with increase in repetition rate. The response rate were higher for the lower repetition rates. Singh et al (2014) also reported better signal-to-noise ratios for lower response rates. Based on the calculations of efficiency, they concluded that a repetition rate of 5 Hz was optimal and most efficient for the clinical recording of oVEMP.

2.9 Effect of stimulus frequency on oVEMP

The stimulus frequency is considered one of the more important parameters for clinical recording of oVEMP. This is owing to the fact that studies have shown significant effect of stimulus frequency on oVEMP amplitudes and/or thresholds (Todd et al., 2009; Lewis et al., 2010; Taylor, Bradshow, Halmagyi, & Welgampola, 2012; Sandhu et al., 2012; Winters, Berg, Grolman, & Klis, 2012; Zhang, Govender, & Colebatch, 2012; Sing & Barman, 2013, 2014). Although most studies have shown that best frequency for oVEMP recording is 500 Hz in healthy individual’s (Sandhu et al., 2012; Winters et al., 2012; Sing & barman, 2013,2014), others have found 1000 Hz as better stimuli (Lewis et al., 2010; Taylor et al., 2012; Zhang et al., 2012). Therefore there appears to be lack of consensus between the studies regarding the best frequency for oVEMP recording.

2.10 Effect of stimulus polarity on oVEMP

Several effects of stimulus polarity on oVEMP has never been studied. However, Papathanssiou et al., (2012) studied effect of stimulus polarity on cVEMP. They reported no significant difference in absolute amplitude and latency between the polarities. Also, there was no significant difference in the inter-aural amplitude ratio between polarities. However, the above study did not evaluate the effect of stimulus polarity on signal-to-noise ratio of cVEMP.

Chapter 3

Method

3.1 Participants

Fifty four healthy individuals (25 males & 29 females) with normal audio-vestibular system in the age range of 18-35 years (mean = 22.7 years; standard deviation = 2.6) were taken as participants for the study. They were included in study after obtaining the informed written consent and their participation in the study did not include any financial implication.

3.1.1 Inclusion criteria.

The audiological well-being of the participants was ensured through a battery of tests which included pure-tone audiometry, speech audiometry, immitance evaluation and auditory brainstem response (ABR). All the participants had pure-tone average of 15 dB HL or less at octave frequencies from 250 Hz to 8000 Hz for air-conduction and 250 Hz to 4000 Hz for bone-conduction. Further, they had ‘A’ type tympanograms and demonstrated presence of ipsilateral and contralateral acoustic reflexes at 100 dB HL at octave frequencies from 500 Hz to 2000 Hz. Additionally, all the participants demonstrated normal auditory brainstem responses (ABRs) by showing normal absolute latencies (I = 1-2 ms; II = 3-4 ms; III = 5-6 ms), inter peak latency difference (I-III & III-IV ≤ 2.2 ms; I-IV ≤ 4.2 ms), inter aural latency difference (≤ 0.2 ms for all three peaks), amplitude ratio (V/I ≥ 1) and wave V latency prolongation between low and high repetition rate (≤ 1 ms between 11.1/s and 90.1/s).

The participants also demonstrated normal vestibular function which was revealed by normal results on Romberg test (no disequilibrium when eyes closed), Fukuda stepping test (less than 45^o deviation about the vertical axis on either side), Tandem gait test (no right or left sway during heel-to-toe walking) and Past pointing test (no overshooting/undershooting when reaching the clinician’s finger and no evident tremors during the task).

3.1.2 Exclusion criteria.

Individuals with visual abnormalities, history of diabetes and/or high blood pressure were excluded from the present study. Individuals with reduced uncomfortable levels (< 100 dB HL for speech) and presence of conductive hearing loss were also excluded. The study also excluded participants with history or presence of neurological, otological or vestibular problems.

3.2 Instrumentation

A calibrated two channel diagnostic audiometer Grason-Stadler Incorporated 61 (GSI-61) with TDH-39 supra-aural headphones housed in MX 41/AR ear cushions was used for air-conduction threshold estimation, speech audiometry and uncomfortable level testing. The same audiometer with Radioear B-71 bone vibrator was used for obataining bone-conduction threshold. A calibrated GSI- tympstar immittance device was used for tympanometry and reflexometry. The Biologic Navigator Pro version 7.0.0 with impedance matched Etymotic ER-3A insert earphones was used to record and analyse ABR and oVEMP waveforms.

3.3 Test environment

Pure-tone audiometry and speech audiometry were carried out in a double room setup whereas ABR and oVEMP were recorded in a single room suit. All these tests were carried out in well illuminated, air-conditioned, acoustically treated rooms with ambient noise levels well within the permissible limits as per American National Standard Institute Guidelines (ANSI S 3.1 1999).

3.4 Procedure

Pure-tone thresholds were obtained at octave frequencies from 250 Hz to 8000 Hz and 250 Hz to 4000 Hz for air- and bone-conduction respectively using modified Hughson-Westlake method (Carhart & Jerger, 1959). Speech audiometry was carried out in participants' native language with standardized test materials. While the speech recognition thresholds were obtained using the bracketing method, the speech identification scores were obtained at the levels prescribed for the test material that was used (usually 40 dB above speech recognition threshold or most comfortable level).

A probe-tone of 226 Hz at 85 dB SPL was used for immittance evaluation. For obtaining the tympanogram, the pressure in the ear canal was varied from -400 to +200 daPa at a pump speed of 50 daPa/s. The ipsilateral and contralateral acoustic reflex thresholds were measured at octave frequencies from 500 Hz to 2000 Hz using the same probe tone frequency as that for tympanometry.

Auditory brainstem responses were acquired to rule out space occupying lesions. Electrodes were placed on the recording sites (non-inverting electrode on the vertex, inverting electrodes on both sides' mastoids and ground on forehead). Absolute elecrtrode impedance of 5 kΩ at each electrode site and the inter electrode impedance of 2 kΩ was ensured. ABR was carried out with rarefaction polarity 100 µs clicks presented at 90 dB nHL using two repetition rates of 11.1/s and 90.1/s The responses were band-pass filtered between 100 Hz and 3000 Hz. The analysis window was set to 10 ms and responses corresponding to a total 1500 stimuli were averaged.

Behavioral balance assessment tests (Rombarg test, Fukuda stepping test, Tandom gait test & Past pointing test) were also carried out for subject selection criteria. Romberg test was performed by asking the individual to stand erect with feet together, eyes closed and hands outstretched in front so that hands were parallel to ground. They were asked to stay in this position for 30 seconds. Presence of sway or inability to perform the task was considered as abnormal results on Romberg test. Fukuda stepping test was administered by asking the individual to stand upright at the center of two concentric circles. The individual was then asked to close the eyes and outstretch hands in front (similar to Romberg test) and march at a place for 50 steps at rate of 1 step/s. A deviation of > 45^o on either side and/or change in position of > 1meter from the starting point were considered as abnormal results on Fukuda stepping test. Tandem gait was administered by asking the individuals to walk on an imaginary straight line such that toes of back foot touch the heel of the front foot at each step. Falling during the task or stretching of hands to prevent falls were considered abnormal results on the test. To perform past pointing test, the individual was seated in a chair. He/she was then asked to alternately touch his/her nose tip and clinician's index finger, the position and distance of which was constantly changed. Presence of tremors during the task and/or undershooting/ overshooting of targets were considered abnormal results on the test.

For acquisition of oVEMP, the subjects were seated comfortably in an upright posture. The electrode sites were cleaned using a commercially available abrasive gel to reduce the skin impedance. Silver chloride disc-type electrodes were placed on the cleaned sites using conduction gel and secured in place using surgical plaster. The non-inverting electrode was placed on the cheek approximately 1cm below the center of the lower eyelid, the inverting electrode was placed 2 cm below the non-inverting electrode and the ground electrode was placed on center of the forehead. This electrode placement was similar to those used previously (Singh & Barman, 2013, 2014, 2015). Absolute and inter-electrode impedance were maintained below 5 kΩ and 2 kΩ respectively. Tone-bursts of 500 Hz (rise/fall time of 2 ms & plateau of 1 ms, intensity of 125 dB peSPL) with three different polarities (condensation, rarefaction, & alternating) were presented monaurally to the contralateral ear in order to evoke oVEMP. The accuracy of the polarity in the output was ensured through the use of a sound level meter connected to an oscilloscope. The sequence of recording for these polarities was randomly changed between the subjects in order to avoid order effect. The repetition rate of the tone-burst presentation was set to 5.1 Hz. The individuals were instructed to maintain an eye gaze in the superomedial direction at about 30^o, a gaze angle found optimal by previous studies (Murnane et al., 2011; Rosengren et al., 2013). The recorded myogenic activity was amplified by a factor of 30000 and band-pass filtered between 1 Hz and 1000 Hz, a filter setting found appropriate previously (Wang, Jaw, & Young, 2013). The analysis window was set to 64 ms, which included a pre-stimulus baseline recording of 10 ms. A total of 150 sweeps were taken for averaging for each run and an average of two replicated waveforms was considered the final waveform for a particular polarity.

3.5 Response analysis

The recorded waveforms of oVEMP were analyzed by two independent experienced audiologists. They were analysed in terms of absolute latencies and peak-to-peak amplitude. The agreement between the audiologists was found to be ≥ 0.9 (Chronbach alpha coefficient). The signal-to-noise ratio was measured using a MATLAB program. Using this program, SNR was calculated using the following formula:

$$\text{SNR} = 20 \log(\text{RMS}_{ep} / \text{RMS}_{b})$$

where ‘SNR’ is signal-to-noise ratio in dB, ‘RMS_{ep}’ is the root-mean-square of the oVEMP response in the time range of 8 to 20 ms and ‘RMS_{b}’ is the root-mean-square of the pre-stimulus baseline (-10 to 0 ms).

3.6 Statistical Analysis

The data of the present study was analysed using statistical package for the social sciences (SPSS) version 16.0. A Chronbach alpha test was done for evaluating inter-judge reliability for peak identification. Descriptive statistics were done in order to obtain mean, standard deviation, range and variance for each of the response parameters. Comparison between ears and polarities was done, therefore two-way repeated measures analysis of variance (two-way repeated measures ANOVA) was used separately for each response parameter. Bonferoni adjusted multiple comparisons were used for pair-wise comparisons of polarities whenever the repeated measures ANOVA demonstrated a significant main effect of tone-burst polarities on a response parameter.

Chapter 4

Results

The present study aimed to evaluate the effect of tone-burst polarity on latencies, peak-to-peak amplitude and SNR of oVEMP waveforms. In order to fulfil the aims of present study, the responses were recorded from 54 healthy individuals. Out of these 54 individuals, oVEMP were present bilaterally for all polarities in 36 individuals and unilaterally in 16 individuals. This accounted for presence of responses in 88 ears (41 left and 47 right ears) out of 108 ears. Therefore the response rate was found to be 81.48% for each of three polarities. Figure 1 shows the individual averaged and grand averaged oVEMP waveforms obtained for the three different polarities from all the participants of the present study.

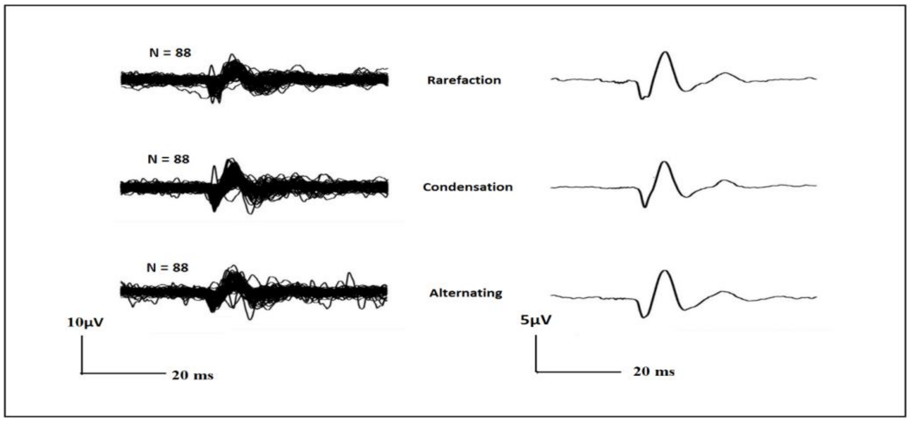

Figure 4.1: Individual averaged and grand averaged oVEMP waveforms recorded for rarefaction, condensation and alternating polarities of tone-burst from 88 ears of 54 healthy individuals.

The obtained responses were analyzed for individual peak latencies (n1 & p1), peak-to-peak amplitude and signal-to-noise ratio in order to fulfil the specific objectives of the present study. The results are discussed below under each of these parameters.

4.1. Effect of tone-burst polarity on n1 latency of oVEMP

The first peak of the biphasic oVEMP waveform, called n1, was identified and latencies were obtained. The descriptive statistics was performed in order to obtain the mean, standard deviation, range and variance of n1 latency. Table 4.1 shows the outcome of the descriptive statistics. It can be observed from the table that there was no apparent difference in n1 latency among the three polarities used in the present study.

Table 4.1: Mean, Standard deviation, range and variance of n1 latencies (in ms) for the three different polarities of tone burst.

Polarity	N	Mean latency	SD	Range	Variance
Rarefaction	88	11.73	0.99	10.13 - 13.78	0.98
Condensation	88	11.93	0.82	11.01 - 14.66	0.68
Alternating	88	11.93	0.86	10.72 - 14.08	0.74

Note: ‘SD’: standard deviation; ‘ms’: milliseconds; ‘N’: number of ears with presence of oVEMP.

A two-way repeated measure ANOVA was done for ear and polarity in order to investigate the statistical significance of the above mentioned observations. The results revealed no significant main effect of polarity [F (2,70) = 1.160, $p > 0.05$] and ear [F(1,36) = 0.724, $p > 0.05$] on n1 latency. However there was a significant interaction between ears and polarity [F(2,70) = 3.132, $p < 0.05$]. Therefore separate one-way repeated measures ANOVA were required for polarities in each ear and for ears under each polarity. The results revealed a significant difference between ears for rarefaction polarity [F(1,35) = 4.80, $p < 0.05$)] but not for condensation polarity [F(1,35) = 0.16, $p > 0.05$] and alternating polarity [F(1,35) = 0.01, $p > 0.05$]. One-way repeated measures ANOVA was also done for polarities in each ear. The results revealed no significant effect of polarities on right ear [F(2,92) = 0.074, $p > 0.08$]. However, there was a significant main effect of polarities in left ear [F(2,80) = 4.25, $p < 0.05$)]. Therefore Bonferoni adjusted multiple comparisons were done for left ear to compare between polarities. The results revealed no significant difference between rarefaction and condensation polarities ($p > 0.05$) and also between rarefaction and alternating polarities ($p > 0.05$). Further there was also no significant difference between condensation and alternating polarity ($p > 0.05$). Figure 4.1.1 shows bar graphs representing mean and 95% confidence intervals of n1 latency of oVEMP for all the three polarities of the present study.

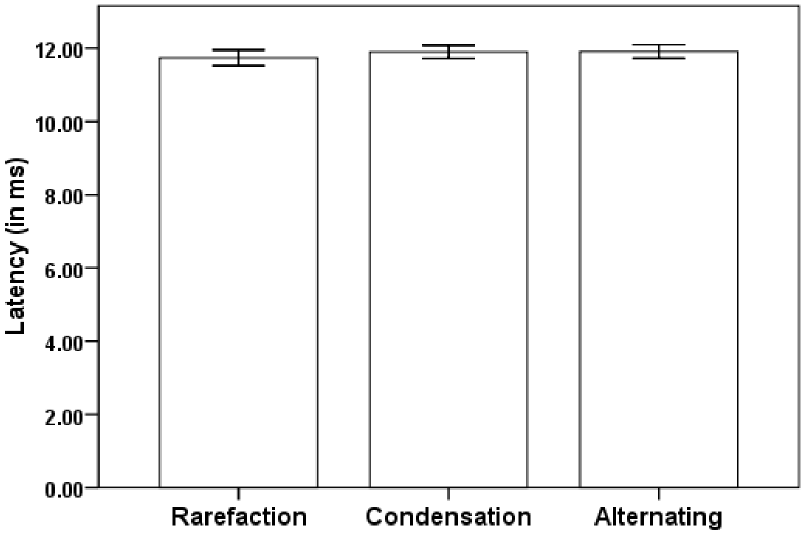

Figure 4.1.1: Mean and 95% confidence intervals of n1 latency of oVEMP as function of tone-burst polarity.

Thus, the Null hypothesis (H_0) that there is no significant effect of tone-burst polarity on latency oVEMP is accepted.

4.2 Effect of tone-burst polarity on p1 latency of oVEMP

The second peak of the biphasic oVEMP waveform, referred as p1, was identified and latencies were obtained. The descriptive statistics was performed in order to obtain the mean, standard deviation, range and variance of p1 latencies. Table 4.2.1 shows the outcome of the descriptive statistics for p1 latency of oVEMP for each of the three tone-burst polarities. It can be observed from the table that there is no apparent difference in the p1 latency of oVEMP among the three polarities.

Table 4.2.1: Mean, standard deviation, range and variance of p1 latency (in ms) of oVEMP for the three different polarities of tone-burst.

Polarity	N	Mean latency	SD	Range	Variance
Rarefaction	88	17.00	0.95	14.08 - 19.18	0.91
Condensation	88	17.22	0.95	15.39 - 19.91	0.92
Alternating	88	17.23	0.88	15.68 - 19.33	0.78

Note: standard deviation; ‘ms’: milliseconds.

In order to evaluate the statistical significance of the above mentioned observation from descriptive statistics, a two-way repeated measures ANOVA was done for polarity and ear. The results revealed no significant main effect of polarity [F(2,70) = 2.89, p >

0.05] and ear [F(1,36) = 0.76, $p > 0.05$] on p1 latency. Further there was also no significant interaction between ears and polarity [F(2,70) = 1.89, $p > 0.05$]. Therefore further pairwise analysis was not taken up. Figure 4.2.1 shows mean and 95% confidence intervals of p1 latency for all the three polarities of tone-burst used in the present study.

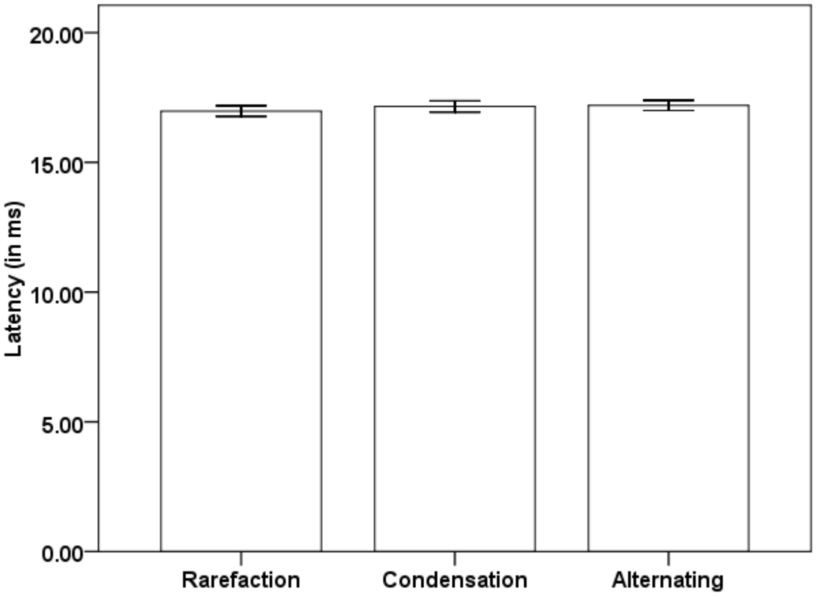

Figure 4.2.1: Mean and 95% confidence intervals of p1 latency of oVEMP as a function of tone-burst polarity.

Thus, the Null hypothesis (H_0) that there is no significant effect of tone-burst polarity on p1 latency of oVEMP is accepted.

4.3 Effect of tone-burst polarity on peak-to-peak amplitude of oVEMP

The amplitude of oVEMP was analyzed in terms of peak-to-peak amplitude rather than the baseline to the peak. The descriptive statistics was performed in order to obtain the mean, standard deviation and variance for peak-to-peak amplitude. Table 4.3.1 shows the outcome of descriptive statistics for peak-to-peak amplitude of oVEMP. As can be seen, the mean values in the table indicate towards lack of difference in peak-to-peak amplitude among the three tone-burst polarities.

Table 4.3.1: Mean, standard deviation, range and variance of peak-to-peak amplitude (in µV) of oVEMP for the three different polarities of tone-burst.

Polarity	N	Mean amplitude	SD	Range	Variance
Rarefaction	88	7.13	4.35	1.63 - 19.88	18.96
Condensation	88	7.49	4.26	0.91 - 18.73	18.19
Alternating	88	7.49	4.49	1.64 - 18.59	20.23

Note. 'SD': standard deviation; 'µV': microvolts.

A two-way repeated measures ANOVA was done for polarity and ears in order to investigate the statistical significance of the above mentioned observation from the descriptive statistics. The results revealed no significant main effect of polarity [F(2,70) = 0.62, $p > 0.05$] and ear [F(1,35) = 0.49, $p > 0.05$] on peak-to-peak amplitude of oVEMP. Further there was also no significant interaction between ears and polarity [F(2,70) = 1.14, $p > 0.05$]. Therefore further pairwise analysis between the polarities was not taken up. Figure 4.3.1 shows mean and 95% confidence intervals of peak-to-peak amplitude of oVEMP for all the three polarities of the present study.

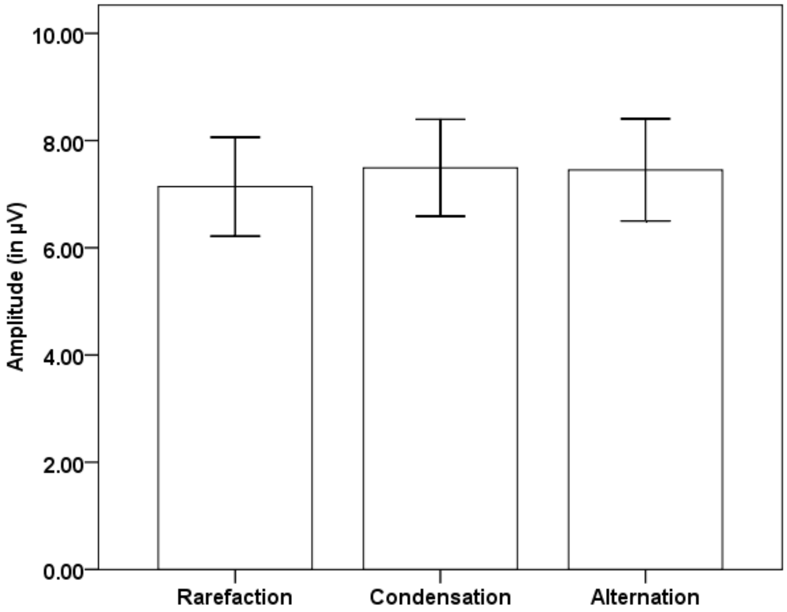

Figure 4.3.1: Mean and 95% confidence intervals of peak-to-peak amplitude of oVEMP as a function of tone-burst polarity.

Thus, the Null hypothesis (H_0) that there is no significant effect of tone-burst polarity on the peak-to-peak amplitude of oVEMP is accepted.

4.4 Effect of tone-burst polarity on signal-to-noise ratio of oVEMP waveforms

The SNR was calculated from each waveform using MATLAB software. The signal-to-noise ratio was estimated by taking the difference of the RMS of the specified time sample of the signal (8 to 20 ms) from the specified time sample in the pre-stimulus baseline (-10 to 0 ms). The descriptive statistics was performed in order to obtain the mean, standard deviation, range and variance of SNR. Table 4.4.1 shows the outcome of descriptive statistic of SNR of oVEMP waveforms. It can be observed from the table that the mean SNR for alternating polarity waveforms appear to be higher than rarefaction and condensation polarities.

Table 4.4.1: Mean, standard deviation, range and variance of SNR (in dB) in the oVEMP waveform for each of the tone-burst polarities.

Polarity	N	Mean amplitude	SD	Range	Variance
Rarefaction	88	19.51	9.69	1.09 - 39.16	94.04
Condensation	88	19.11	10.45	1.24 - 41.75	109.24
Alternating	88	21.79	10.08	1.37 - 46.17	101.76

Note. 'SD': standard deviation; in 'dB' decibel.

A two-way repeated measure ANOVA was done to study the ear differences and effect of tone-burst polarity on SNR of oVEMP waveforms in order to investigate the statistical significance of the above observations. The results revealed no significant effect of polarity [F(2,70) = 1.27, $p > 0.05$] and ear [F(1,35) = 1.25, $p > 0.05$] on SNR of oVEMP waveforms. However there was a significant interaction between ears and polarity [F(2,70) = 3.18, $p < 0.05$]. Therefore separate one-way repeated measures ANOVA were performed for polarity in each ear and for ears under each polarity. The results revealed a significant main effect of ears on SNR in rarefaction polarity [F(1,35) = 7.35, $p < 0.05$)]. However there was no significant main effect of ears on SNR in condensation polarity [F(1,35) = 0.51, $p > 0.05$] and alternating polarity [F(1,35) = 0.14, $p > 0.05$]. One-way repeated measures ANOVA were also done for polarities in each ear. The results revealed no significant main effect of polarity on SNR in right ear [F(2,92) = 2.49, $p > 0.05$] as well as left ear [F(2,76) = 2.27, $p > 0.05$)]. Therefore, further pairwise analysis using

Bonferroni adjusted multiple comparisons was not taken up. Figure 4.4.1 shows mean and 95% confidence intervals of SNR for each of the three polarities of tone-burst used in the present study.

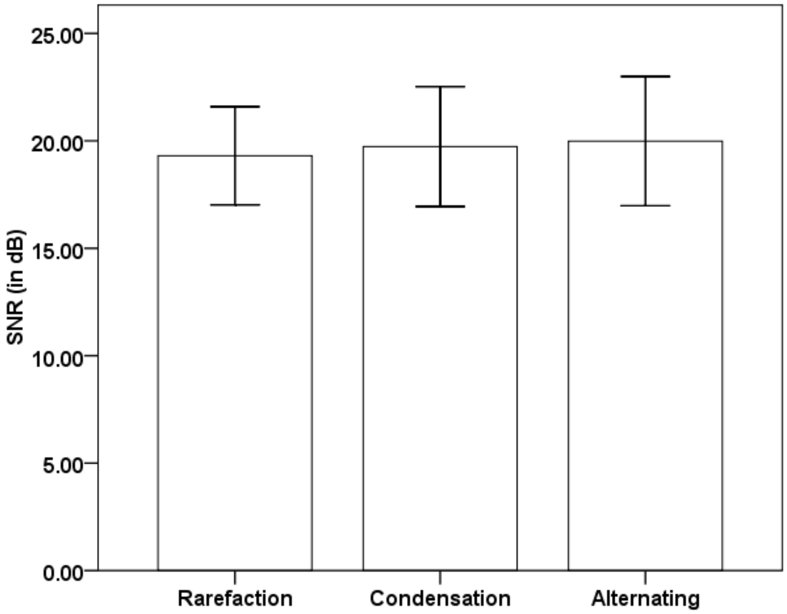

Figure 4.4.1: Mean and 95% confidence intervals of SNR of oVEMP waveforms as a function of tone-burst polarity.

Thus, the Null hypothesis (H_0) that there is no significant effect of polarity of tone-burst on SNR of oVEMP waveforms is accepted.

Overall, the results of the present study revealed that there was no significant effect of tone-burst polarity on individual peak latencies, peak-to-peak amplitude of oVEMP and signal-to-noise ratio of oVEMP waveforms. However, there was a significant difference in peak-to-peak amplitude and signal-to-noise ratio (SNR) between the ears for rarefaction polarity alone.

Chapter 5

Discussion

The contralateral oVEMPs were recorded for tone-bursts of three different polarities (rarefaction, condensation, & alternating) from 54 healthy individuals. The absolute latencies, peak-to-peak amplitude and signal-to-noise ratio were measured for each of the three tone-burst polarities.

The results showed overall response rate for contralateral recording to be 81.48% for all the three polarities. Further there were no discrepancies in response presence/absence between the polarities in any participant. It means that those who had presence of oVEMP, had it for all three polarities and those in whom the responses were absent, they were absent for all the three polarities. Although there are no previous studies exploring the effect of stimulus polarity on response rate of oVEMP, several studies have used one of the three polarities. The response rate for rarefaction polarity to elicit oVEMP was found to be 100% (Xie et al., 2014; Kamali et al 2013). Likewise, the alternating polarity showed response rate of 100% (Singh & Barman 2013, 2014; Kantner, et al., 2012) and so did the condensation polarity (Dennis et al., 2014). Although the repetition rate in the present study was slightly lower than these studies, the lack of difference in repetition rate between the polarities between the studies was similar. Therefore the results of the present study are similar to those of the above mentioned studies.

5.1 Effect of tone-burst polarity on latency of oVEMP

Absolute latencies of oVEMP (n1 & p1) were measured for three tone-burst polarities and the data was subjected to statistical analyses. The results revealed no significant difference in n1 as well as p1 latency between the three polarities. There are no previous studies regarding the effect of tone-burst polarity on oVEMP latencies. Nevertheless, the findings of the present study is in agreement with a study on effect of polarity on cVEMP (Papathanassiou et al., 2012), which also reported no significant changes in the absolute latencies of cVEMP with changes in the tone-burst polarity. However, this is in dissonance with the reports about the effect of stimulus polarity on the latency of peaks of the other auditory evoked potentials like electrocochleography (ECochG) (Hughes, Fino, & Gagnon, 1981; Salt & Thornton, 1984) and ABR (Don, Vermiglio, Ponton, Eggermont, & Masuda, 1996). In the above mentioned studies, low frequency tone-bursts at high intensity were reported to show considerable phase effects on the latencies of the peaks of the three potentials (Hughes et al., 1981; Salt & Thornton, 1984). The differences in the findings between the VEMP studies [present study & the study by Papathanasiou et al (2012)] and other auditory evoked potentials could be attributed to the differences in the physiological aspects of stimulation between the end organs of generation of VEMP (utricle & saccule) and those for ECochG and ABR, which arises from cochlea.

In the cochlea, a basilar membrane movement towards the scala vestibuli produces depolarization (excitation) whereas the movement towards the scala tympani causes repolarization and/or hyperpolarization (Dallos, 1992). In the rarefaction polarity, the basilar membrane first moves towards the scala vestibuli which produces excitation. In the condensation polarity, the basilar membrane moves first towards the scala tympani which results in hyperpolarization and then towards the scala vestibuli that causes excitation (Dallos, 1992). This leads to a time difference in the excitation of the neuron between two polarities which causes a latency difference of peaks between rarefaction and condensation polarities for cochlear evoked potentials. However in the utricle, the stereocillia are arranged across an imaginary line called striola and the movement of these stiriocillia are antagonistic to each other across the striola for the same stimulation (Jacobson, 1993). This means that any vibration or movement of the utricular macula will result in excitation in one half the utricle whereas inhibition in the other half (Jacobson, 1993). Therefore irrespective of the stimulus polarity, there is likely to be no difference in the latencies of the peaks produced from the utricular stimulation, in this case oVEMP. Thus the findings of no significant difference in the absolute latencies of oVEMP peaks is justified.

5.2 Effect of tone-burst polarity on peak-to-peak amplitude of oVEMP

The present study also measured the effect of different tone-burst polarities on peak-to-peak amplitude of oVEMP waveforms. The results showed no significant difference in peak-to-peak amplitude of oVEMP between the three polarities. There are no previous studies regarding the effect of tone-burst polarity on peak-to-peak amplitude of oVEMP. Nevertheless, this is in consonance with the only study exploring the effect of varying stimulus polarity on cVEMP (Papathanassiou et al., 2012), a close associate of oVEMP as both the potentials are otolith generated myogenic potentials. This is also in agreement with the studies on effect of stimulus polarity on the other auditory evoked potentials like ECochG and ABR (Emerson, Brooks, Parker, & Chiappa, 1980; Hughes et al., 1981).

The lack of difference in peak-to-peak amplitude between polarities might be attributed to the effect of changes in stimulus polarity on the power spectrum of the stimulus. Irrespective of the changes in the stimulus polarity, the overall energy, which is responsible for the amplitude of a potential, remains the same (Gorga, Kaminsky, & Beanchaive, 1991). Since the amplitude is dependent on the energy within the stimulus spectrum (Murnane et al., 2011) there will be no metamorphosis of the response amplitude with changes in the stimulus polarity.

5.3 Effect of tone-burst polarity on signal-to-noise ratio of oVEMP waveforms

The present study evaluated the effect of three different tone-burst polarities on signal-to-noise of oVEMP waveforms. The results showed no significant difference in signal-to-noise ratio between the three different polarities. There are no studies exploring the effect of tone-burst polarity on the signal-to-noise ratio of oVEMP. Even the study on cVEMP mentioned above (Papathanassiou et al., 2012) and the studies exploring the effect of stimulus polarity on other auditory evoked potentials like ECochG and ABR (Emerson, Brooks, Parker, & Chiappa, 1980; Hughes et al., 1981) did not explore the changes in the SNR in the waveforms of these potentials.

The lack of difference in the signal-to noise ratio between the tone-burst polarities could be justified based on the concept that signal-to-noise ratio depends upon the amplitude of the response and level of noise. In present study there was no significant difference in the peak-to-peak amplitude of oVEMP between the polarities. Although noise is a random phenomenon, in controlled acoustic environment like the acoustically treated rooms and with subjects' activity level under check, this is likely to remain nearly constant during the recordings for different polarities. Therefore lack of difference in response amplitude and also the noise may be the reason for the lack of differences in signal-to-noise ratio between the three polarities.

Chapter 6

Summary and Conclusion

Ocular VEMP is an excitatory muscle potential which can be recorded from the surface electrodes placed on the skin overlying the inferior oblique muscle (Todd et al., 2007). oVEMP is characterized by an initial negative peak at 10–12 ms (n10 or n1) and a subsequent positive peak at 15-20 ms (p15 or p1) post stimulus onset (Chihara et al., 2007; Walther et al 2011). oVEMPs are largely believed to represent the functioning of the utricle and the VOR pathway that initiates from the otolith organs (Chihara et al., 2007, 2009). This makes it an important test within the test battery for vestibular assessment as these structures are not evaluated when using tests like bithermal caloric evaluation (Capps, Preciado, Paparella, & Hoppe, 1973) and cervical VEMP (Colebatch & Halmagyi, 1992; Colebatch et al., 1994).

In addition to the pathologies affecting utricle and the VOR pathway, oVEMP can also be affected by several subject and stimulus related factors. One of the stimulus related factors that might be potentially affecting oVEMPs but has been previously ignored by researcher's world over is stimulus polarity. Several studies have used rarefaction (Xie et al., 2014; Kamali et al 2013), condensation (Denniset al., 2014), and alternating (Singh & Barman 2013, 2014, Kantner et al., 2012) polarities and have shown differences in various response parameters of oVEMP. One of the factors that potentially might have caused differences in the response could be the stimulus polarity. However, there is scarcity of studies that have investigated the effect of stimulus polarity on oVEMP. Thus, the present study aimed at examining the effect of stimulus polarity on latencies, amplitude and signal-to-noise ratio of oVEMP.

In order to fulfill the aim and objectives of the present study, oVEMPs were recorded from 54 healthy individuals in the age range of 18-35 years by placing surface electrodes beneath the eyes (non-inverting 1 cm below the lower eyelid & inverting 2 cm below the non-inverting) and forehead (ground). The responses were obtained using tone-burst of 500 Hz (rise/fall time of 2 ms & plateau of 1 ms; intensity of 125 dB peSPL) with three different polarities (condensation, rarefaction, & alternating). The stimuli were presented monaurally to the contralateral ear in order to evoke oVEMP. The repetition rate of the tone-burst presentation was set to 5.1 Hz. The recorded myogenic activity was band-pass filtered between 1 and 1000 Hz and amplified by a factor of 30000. The analysis window was set to 64 ms, which included a pre-stimulus baseline recording of 10 ms. A total of 150 sweeps were taken for averaging.

The absolute n1 and p1 latencies, peak-to-peak amplitude and signal-to-noise ratio were measured. Two-way repeated measures ANOVA were used for each response parameter for the statistical comparison between the ears and polarities. In case of a significant interaction between ears and polarity, separate ear-wise analysis for each polarity and separate polarity-wise analysis in each ear were performed using one-way repeated measures ANOVA in order to resolve the interaction effect. Bonferroni adjusted multiple comparisons were used for pair-wise comparisons of polarities whenever the repeated measures ANOVA demonstrated a significant main effect of tone-burst polarities on a response parameter.

The results revealed no significant difference in n1 and p1 latencies between the three polarities. This could be attributed to the physiological aspects of utricle. Vibrations or movement of utricular macula for different stimulus polarities shows no time difference in excitation of neuron owing to the occurrence of both excitation and inhibition across the striola in the same utricle (Jacobson, 1993). Therefore latencies for different stimulus polarity show no significant difference.

Further, the results showed no significant difference in peak-to-peak amplitude of oVEMP between the polarities. The lack of difference in peak-to-peak amplitude between polarities might be attributed to the effect of changes in stimulus polarity on the power spectrum of the stimulus. Irrespective of the changes in the stimulus polarity, the overall energy, which is responsible for the amplitude of a potential, remains the same (Gorga et al., 1991). Since the amplitude is dependent on the energy within the stimulus spectrum (Murnane et al., 2011), the lack of difference in amplitude could be explained.

The signal-to-noise ratio of the oVEMP waveforms were compared between the polarities and the results demonstrated no significant difference in SNR between the polarities of tone-burst. The lack of differences in the signal-to noise ratio between the polarities could be justified based on the concept that signal-to-noise ratio depends upon the amplitude of the response and level of noise. In present study there was no significant difference in the peak-to-peak amplitude of oVEMP between the polarities. Although noise is a random phenomenon, in controlled acoustic environment like the acoustically treated rooms and with subjects’ activity level under check, this is likely to remain nearly constant during the recordings for different polarities. Therefore lack of difference in response amplitude and also the noise may be the reason for the lack of differences in signal-to-noise ratio between the three polarities.

Therefore from the above discussion, it can be concluded that tone-burst polarity does not affect the oVEMP response parameters. This implicates that oVEMP can be obtained using any of the three polarities (rarefaction, condensation & alternating) when recording oVEMP clinically.

In the present study, the participants were taken in the age range of 18-35 years. This age range is not the typical age range for vestibular patients. Typically vestibular pathologies affect in the 5th and 6th decades of life (Johnson, 1971; Niekdecker, Pfaltz, Malefic, & Benz, 1981; Walther & Westhofen, 2007; Shojaku et al., 2009). Occasionally some stimulus parameters like frequency have been found to interact with age (Piker, Jacobson, Burkard, McCaslin, & Hood, 2013). It is not yet known if the tone-burst polarity will have any interaction with age and therby affect the results differently in different age groups. Therefore future studies might benefit from studying the effect of stimulus polarity in a broader age range of participants in order to evaluate if such an interaction does occur.

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