# EVALUATION OF UTRICULAR FUNCTION USING OCULAR VESTIBULAR EVOKED MYOGENIC POTENTIALS AND SUBJECTIVE VISUAL VERTICAL TEST IN INDIVIDUALS WITH SENSORINEURAL HEARING LOSS WITHOUT VESTIBULAR DISEASE

Acharekar Rashmi Madhukar

17AUD003

This Dissertation is submitted as a part of fulfillment

for the Degree of Master of Science in Audiology

University of Mysore, Mysore

**All India Institute of Speech and Hearing**

**Manasagangothri Mysore – 570006**

**May 2019**

## CERTIFICATE

This is to certify that this dissertation entitled **'Evaluation of utricular function using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with sensorineural hearing loss without vestibular disease'** is the bonafide work submitted in part fulfillment for the Degree of Master of Science (Audiology) of the student with Registration No: **17AUD003**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

**Dr. M. Pushapavathi**
**Director**
All India Institute of Speech and Hearing,
Manasagangothri, Mysuru- 570 006.

Mysuru
May 2019

## CERTIFICATE

This is to certify that this dissertation entitled **'Evaluation of utricular function using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with sensorineural hearing loss without vestibular disease'** is bonafide work submitted as a part for the fulfillment for the degree of Master of Science (Audiology) of the student Registration Number: **17AUD003**. This has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other University for the award of any other Diploma or Degree.

**Dr. Sujeet Kumar Sinha**

**Guide**

Reader in Audiology,

Department of Audiology,

All India Institute of Speech and Hearing,

Manasagangothri, Mysuru- 570006.

Mysuru,

May 2019

## DECLARATION

This is to certify that this Master's dissertation entitled **'Evaluation of utricular function using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with sensorineural hearing loss without vestibular disease'** is the result of my own study under the guidance of **Dr. Sujeet Kumar Sinha**, Reader in Audiology, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier in other University for the award of any Diploma or Degree.

Mysuru,

May 2019

**Acharekar Rashmi Madhukar**

Reg No:17AUD003

Dedicated to my mumma,
pappa and my guide

# ACKNOWLEDGMENTS

Firstly, I would like to express my sincere gratitude to my loving parents and my brother (**Rohan dada**). Without their constant support and encouragement, it wouldn't have been possible to complete my masters. Thank you for giving me the strength to survive away from home and learning to be independent. Love you **mumma, pappa and dada.** I can proudly say that I'm blessed with best parents in the world.

Secondly, I would like to extend my heartfelt gratitude to my guide **Dr. Sujeet Kumar Sinha**. Sir, without your guidance it wouldn't have been possible. You solved all my silly queries. Thank you for providing me a chance to get equipped with a new equipment. The way you teach makes the toughest things easy and interesting! I consider myself fortunate to have a teacher like you. Thank you Sir.

I thank all the subjects who participated in the study without whom this work would not have been possible.

I express my sincere gratitude to all my teachers here in AIISH, who have imparted knowledge and moral values in me. You are the best! Thank you **Sandeep sir, Prashanth sir, Asha mam and Ajith Sir** for inspiring me to strive harder and keep doing better every time. **Vikas sir** it was so much fun in clinics with you. You have imparted some fine clinical skills in me. Thank you! Thank you for your love **Rajalakshmi mam**.

My family here in Mysuru….**Sneh (Sneha), Moh (Mohini), Chendu (Chhandasi), Shitu (Shital), Gappu (Jagrati) & Sankya (Sanket)**. Thank you for all the sweet memories you all gave me. You all stood by me whenever I felt low. Those crazy unforgettable moments, laughing till our stomach hurts, long discussions, cooking in hostel.. all this will be cherished forever. When I think about my college days, I can proudly say I had the best crazy days of my life with you guys. I'm gonna miss you all badly.

My UG batchmates, **Rakhya (Rakhi), Yash (Yashashree), Sankya, Mohini, Alisha, Chhandasi, Dost Anshul, Palak, Moni, Ruhee ….**you guys have given me some beautiful memories to cherish for lifetime.

My dissertation partners **Momo and Santy**, thank you guys for supporting throughout. Those pani puri breaks were so much fun.

Thank you **Neha, Sridhar and Biswa** for helping me find subjects for data collection. I would like to thank **Pooja** my favourite junior for helping me with kannada to call subjects for data collection and all my juniors who participated in the study.

Thank you, **Ajay** for being there. Thank you for supporting always and getting home cooked food whenever I felt home sick. You are the best CR. **Abinaya** you are a strong girl. You will always be remembered in warm thoughts of mine.

**Aswini** you are a sweet girl. Thank you for helping me time and again. **Anks** thanks for your kind words during stressful days. Talking to you for five minutes would lift up my mood. **Moni**, my dearest friend thank you for being there since the first day of my bachelors. **Bhagyashree (Bhagya**) my friend since school….thanks for being there.

Thank you **mama** for taking care of me like your own daughter. Thank you baba for your kind blessings.

Last but not the least, journals, AIISH digital repository and Google, you have given me tonnes of knowledge. Thank you!

**ABSTRACT**

Aim: The aim of the study was to assess the functioning of utricle using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with various degrees of sensorineural hearing loss.

Methods: Two groups of participants were taken for the study. Group I consisted of 28 participants (12 males and 18 females) with various degree of sensorineural hearing loss within the age range of 18-40 years. Out of 28 participants, 9 participants had minimal to mild sensorineural hearing loss, 9 participants had moderate to moderately severe sensorineural hearing loss and 10 participants had severe to profound sensorineural hearing loss. Group II consisted of 28 participants with normal hearing (12 males & 18 females) within the age range of 18-40 years. All the participants in both the groups underwent a detailed case history, pure tone audiometry, immittance audiometry and acoustic reflex threshold test, oVEMP and SVV.

Results: oVEMP was present in 100% of the participants in normal hearing group and in the hearing loss group oVEMP was present in 64% (18 out of 28) of right ears and 67% (19 out of 28) of left ears. There was no consistent pattern of latency prolongation or amplitude reduction of oVEMP in individuals with different degree of hearing loss. There was a significant association between degree of hearing loss and absence of oVEMP responses i.e as the degree of hearing loss increased, the number of oVEMP absent responses also increased. The mean ocular tilt of individuals with normal hearing was almost similar to individual with hearing impairment except for the bilateral moderate to moderately severe sensorineural hearing loss group where the ocular tilt was slightly larger. However, the ocular tilt of both the groups are within the normal range.

Conclusions: Individuals with hearing loss may have utricular dysfunction and individuals with higher degree of hearing loss may have more utricular dysfunction. The SVV may not be an ideal test in finding out the ocular tilt in individuals with bilateral symmetrical sensorineural hearing loss. However, the utricular evaluation must be carried out in individuals with different degrees of hearing impairment.

**Table of Contents**

## List of Tables

## List of Figures

# CHAPTER I

# INTRODUCTION

Hearing loss is considered among the leading health concerns around the world. According to the World Health Organization (WHO), 466 million people worldwide have disabling hearing loss. Vestibular disturbances have also been reported in individuals with hearing loss.

The inner ear contains two sensory organs namely, auditory and vestibular, connected anatomically and functionally encased within same membranous labyrinth and also shares common labyrinthine artery and same endolymphatic fluid. Therefore, damage or insult to one of the systems can bring about damage to the other system as well. The vestibular system is broadly categorized into both peripheral and central components. The peripheral system is bilaterally composed of three semi-circular canals (posterior, superior, lateral) and the otolithic organs (saccule and utricle). The semi-circular canals detect rotational head movement while the utricle and saccule respond to linear acceleration and gravity, respectively.

Ocular vestibular-evoked myogenic potential (oVEMP) is a test which evaluates for the utricular function has recently been introduced and validated. oVEMP determines the functioning of the utricle and the superior vestibular nerve function. It has been found to be useful in assessing patients with a utricular disorder like Meniere's disease 80%, vestibular neuritis, labyrinthitis and in superior semi-circular canal dehiscence syndrome (Shin et al., 2012, Niesten et al., 2013).

Subjective Visual Vertical test assesses the ability to perceive verticality which depends on visual, vestibular and somatosensory inputs. The subjective visual vertical is determined by having subjects adjust a visible luminous line in complete darkness to what they consider to be upright, earth vertical. The subjective visual vertical (SVV) is a perception often impaired in patients with neurologic disorders and is considered as a sensitive tool to detect otolithic dysfunctions. It has been widely demonstrated that patients with vestibular disorders and encephalic lesions often present pathological tilts of SVV. (Min et al., 2007; Vibert et al., 1999; Tarnutzer et al., 2012). Since oVEMP and subjective visual vertical test assesses the utricular function, the administration of two tests together will give us insights on the functioning of the utricular function in individuals with hearing loss.

## 1.1 Need of the study

### *1.1.1 Need of the vestibular studies in SNHL*

The cochlea and vestibule share a continuous membranous structure and similar receptor cell ultra-structures (Zhou, Wu, & Wang, 2016). There is a great association between vestibular and balance disorders with the sensorineural hearing loss as it is anatomically related. The patients with sensorineural hearing loss (SNHL) are likely to have subclinical disorders of the vestibular system. Disorders of the inner ear may result in a variety of manifestations, including vertigo, spatial disorientation, blurred vision, impaired articulation, and hearing impairment.

There are numerous reports of vestibular and balance dysfunction in hearing-impaired children found in the literature, most studies fail to control for type, degree, and etiology of the hearing loss, as well as for other confounding variables. The prevalence of vestibular dysfunction in children with severe to profound hearing loss was found to be 18.75% (Wolter, 2016). Children with unilateral deafness also displayed significantly poorer balance function than their normal-hearing peers (Wolter, 2016). The prevalence of vestibular impairment in children and individuals with sensorineural hearing loss (SNHL) is high, ranging between 20 and 70 percent (Cushing et al., 2013). Considering the diversity of clinical symptoms associated with hearing loss with otolithic dysfunction, the objective means of testing the function of otolithic organs should be recommended for the hearing-impaired patient

*1.1.2 Need for studying oVEMP in SNHL*

Click-evoked VEMPs are reported to be attenuated or absent in a proportion of patients with vestibular neuritis, herpes zoster oticus, late Meniere's disease, and vestibular schwannomas; their amplitudes are increased and thresholds are pathologically lowered in superior semicircular canal dehiscence presenting with the Tullio phenomenon (Welgampola, 2005). VEMPs evoked by clicks and direct current are useful when monitoring the efficacy of intratympanic gentamicin therapy used for chemical vestibular ablation.

VEMP methods are excellent to distinguish between neuritis in the superior (oVEMP) and the inferior branch (cVEMP). oVEMP has been able to identify vestibular neuritis in superior vestibular nerve accurately which is the most common cause of vertigo with an incidence of 3.5/100000 (Rosengren et al., 2008). VNG and VEMP examination indicated that vestibular neuritis mainly affected the superior division of the vestibular nerve, which innervates the horizontal semi-circular canal and anterior semi-circular canal (Chen, Young & Wu, 2000).

Rauch (2004) reported that the rate of VEMP abnormalities in the control ears was significantly lower than the corresponding rates in the affected BPPV ears and the affected Meniere's ears. Meniere's ears display alterations in vestibular evoked myogenic potential threshold and tuning. Unaffected ears of unilateral Meniere's subjects show similar changes, though to a lesser degree. In cases of Meniere's disease, the oVEMP amplitude is reported increased in relation to a Meniere's attack, while it is normalized in a quiet phase (Manzari et al., 2010).

Studies report that oVEMPs are abnormal, more than cVEMPs when tested in individuals with BPPV, suggesting utricular involvement (Singh and Apeksha, 2016, Xu et al., 2016). Increased oVEMP amplitude is also suggested as an objective parameter to evaluate if reposition maneuvers were successful (Bremova et al., 2013). BPPV is a disease of the labyrinth, ie, a peripheral organ disease, and VEMP recordings in BPPV patients were found to be either normal or absent, or with delayed latencies.

Bansal, Sahni and Sinha (2013) studied oVEMP and cVEMP in 23 individuals with severe to profound sensorineural hearing loss and found that oVEMP was absent in 15 out of 45 ears of the subjects. The author concluded that utricular function is more linked with the cochlea compared to that of the saccule.

cVEMPs and oVEMPs have been found to be useful in diagnosis of the saculocollic and utriculo-ocular pathways, respectively, in Meniere's disease, vestibular neuritis, superior canal dehiscence syndrome, auditory neuropathy, and labyrinthitis. (Zhou 2009; Murfoshi 2011; Bansal 2013, Zuniga 2013). Thus, oVEMP helps in diagnosing various vestibular disorders and it is also reported that vestibular dysfunction is overwhelmingly prevalent in children with sensorineural hearing loss (O'Reilly et al., 2010). However, the number of vestibular studies in sensorineural hearing loss reported in the literature are very less. So, there is a need to carry out more vestibular studies in individuals with sensorineural hearing loss.

*1.1.3 Need for studying Subjective visual vertical (SVV) in individuals with SNHL*

SVV is a simple, noninvasive test that provides a valuable contribution to the assessment of peripheral vestibular function. SVV is frequently tilted in acute peripheral vestibulopathies. These findings suggest that otolithic function is implicated in the deficit depending on the extent and/or the localization of the peripheral vestibular lesion (Vibert et al 1999). SVV was found to be affected that is significant deviations of the subjective vertical towards the affected ear was found in 100% of the patients with vestibular nerve section and Ramasey hunt syndrome, in 89% individuals with vestibular neuritis and 0% of individuals with BPPV as reported by Böhmer and Rickenmann, (1995). Transient abnormalities in the SVV have also been reported in adults with sudden unilateral SNHL (Ogawa et al., 2012). However, the amount of SVV studies in sensorineural hearing loss reported in the literature are very less. So, there is a need to carry out more vestibular studies utilizing the SVV in individuals with sensorineural hearing loss.

**1.2 Aim of the study**

The aim of the present study was to assess the functioning of utricle using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with various degrees of sensorineural hearing loss.

**1.3 Objectives of the study**

1. To assess the functioning of the utricle in individuals with sensorineural hearing loss using oVEMP and Subjective visual vertical test (SVV).
2. To find out the correlation between ocular VEMP and SVV test findings in individuals with various degree of sensorineural hearing loss.
3. To find out an association between severity of hearing loss with ocular VEMP test findings in individuals with various degree of sensorineural hearing loss.

# CHAPTER II

# REVIEW OF LITERATURE

The inner ear encompasses two important sensory organs, an organ of hearing and another for balance. The auditory system helps us in hearing and the vestibular system helps in detecting and maintaining spatial orientation and stabilizes vision to maintain balance, particularly when there is movement. The vestibular system comprises of semi-circular canals and the otolith organs -utricle and saccule. The three semi-circular canals sense angular acceleration whereas the utricle and saccule sense linear acceleration. The utricle and saccule also contribute to the sense of verticality.

After injury to the otoliths, or to the nerve that transmits impulses from the otoliths and other parts the ear to the brain, judgement of vertical may be altered, which literally tilts one's vision. A person with vestibular disease may not perceive a vertical line as vertical resulting in deviation from normal which can be measured in degrees. Studies have reported that the hearing loss is also accompanied by vestibular symptoms like vertigo and nausea. It is therefore necessary to assess the utricular function in such individuals who report of hearing loss. The utricle can be assessed with the help of ocular vestibular evoked myogenic potentials and subjective visual vertical test.

Subjective Visual Vertical (SVV) is the ability of a person to perceive verticality. The purpose of SVV test is to detect abnormal subjective tilt. In humans, the perception of vertical is provided by input from the otolithic organs and graviceptive pathways. A person with vestibular disease may not perceive a vertical line as vertical resulting in deviation from normal which, can be measured in degrees. A commercial method of measuring SVV involves a laser line projected onto a screen. The angle of the line with respect to a reference can be read out by the tester. By allowing a subject to repeatedly set the line to vertical, one can measure SVV. There are many tests for SVV which includes: Maddox rod, vertical beam projected on screen, motor driven hemisphere with dots, etc.

Subjective visual vertical and Subjective Visual Horizontal (SVH) are well-studied tests that examine a subject's perception of tilt of the external world, and abnormal test scores may reflect an imbalance in static utricular function leading to a perceived tilt in the roll plane. Abnormalities in SVH have been correlated with asymmetry in oVEMP in patients with Ménière's disease, corroborating their potential shared physiologic basis (Lin & Young ,2011). Initially the perception of subjective visual vertical and subjective visual horizontal would be tested with 'the bucket test'.

The bucket test was first described by Zwergal (2009), in which the subject adjusts the bucket so that the radium light inside it will appear straight. The deviation from the gravitational vertical is noted by the examiner outside on the bottom of the bucket where a protractor print is pasted. An average of six trials is taken as absolute value. Normal range of deviation is 0 ± 3°.

Friedmann (1970), studied subjective vertical in a variety of clinical situations. Normal subjects can adjust an illuminated rod in an otherwise completely dark room to vertical within a mean error of less than 2°. The author concluded that severe derangement of this test is confined to brainstem lesions and the immediate postoperative period of peripheral vestibular lesions.

## 2.1 Clinical applications of subjective visual vertical test on peripheral vestibular disorders:

### *2.1.1 Meniere's disease*

Pagarkar and Ridout (2008) examined the relationship between the direction of deviation of the linear marker (preset angle) and measured subjective visual vertical and subjective visual horizontal values in 10 subjects with unilateral Meniere's disease. 5 out of 10 participants (50%) had an abnormal mean subjective visual vertical and subjective visual horizontal value. The authors concluded that the perception of vertical orientation and horizontal orientation is affected in 50% of the participants with Meniere's disease.

Kumagami et al. (2009) investigated subjective visual vertical (SVV) in individuals with definite Meniere's disease during the attack of Meniere's disease in 22 participants. The test was performed before, at, and after acute Meniere's attack. Out of 22 cases, 14 showed abnormal tilts of SVV in acute attacks. The tilts were toward the side of the affected ear in 13 participants and these abnormal tilts returned to normal within a few weeks after the acute attacks. The authors concluded that subjective visual vertical can be used as a good tool for the evaluation of otolith dysfunction at acute attacks in patients with Meniere's disease.

Chetana and Jayesh (2015) recorded SVV in 11 cases diagnosed as Meniere's syndrome. The cases were in varying stages of the disease, and two of the subjects had bilateral Meniere's disease. The results showed that 55 % of these patients had abnormal SVV and amongst 50 % of them, the tilt was to the same side as the disease. In bilateral Meniere's disease SVV was insensitive to lateralization. The author concluded that in patients with Meniere's disease, a marked deviation toward the operated side was found acutely, with resolution over weeks.

*2.1.2 Benign paroxysmal positional vertigo*

Bohmer and Rickennman (1995) administered SVV in 19 patients suffering from BPPV and found that SVV was normal in all subjects except in one subject who had borderline tilt. Gall, Ireland, and Robertson (1999) studied SVV in 16 subjects with posterior canal BPPV at baseline, post hallpike and semont maneuevers and at follow-up two weeks later. The results showed that 10 out of 16 patients showed a statistically significant change in SVV post maneuevrs. The author concluded that the inferior vestibular nerve may to some degree influence the ocular tilt reaction.

Cohen and Haghpeykar (2012) examined if patients with unilateral benign paroxysmal positional vertigo (BPPV) differ from normal subjects in subjective visual vertical test. They studied 25 patients with unilateral, posterior canal BPPV using the traditional bucket test and found that in some of the participants with BPPV, the SVV test was different compared to the normals. The authors concluded that although the bucket test is not useful in detecting the vestibular lesions in all the participants with vestibular lesion.

Chetana and Jayesh (2015) studied 42 patients diagnosed as BPPV of which 86 % had posterior canal BPPV and 14 % had lateral canal BPPV. The results revealed that at first visit, 71 % of the subjects showed abnormal SVV towards affected side, 19 % had normal SVV and in rest, the tilt was to opposite side. It was also found that after treatment by canal repositioning manuevers, 17 % showed a normal SVV. The author concluded that the tilt in SVV probably reflects unilateral utricular disturbance and that static SVV is a useful measure of utricular dysfunction in acute peripheral disorders with a potential use in measuring compensation, prognosis and recovery in various peripheral vestibular conditions.

*2.1.3 Vestibular neuritis*

Vibert and Safran (1999) measured SVV in individuals suffering from vestibular neuritis after surgical correction using binocular test and monocular test. The authors found that SVV in tilted in individuals with vestibular neuritis and concluded that otolith function is affected in individuals with vestibular neuritis depending upon the extent and/or localisation of the peripheral vestibular lesion.

Noh and Chae (2007) studied 62 subjects with unilateral vestibular neuritis using SVV test. SVV test was administered during the acute period and sequentially followed during the recovery period. The results revealed abnormal tilt on either side and that the range of abnormal tilt improved as the dizziness symptoms improved. The author concluded that SVV correlated with clinical improvement of dizziness symptoms in vestibular neuritis.

Min et al. (2007) evaluated 35 subjects with unilateral vestibular neuritis using Subjective visual vertical and Subjective visual horizontal in acute period and 4 weeks after rehabilitation. The results showed that SVV was deviated to the lesioned side and the mean deviation was 3.51 degrees. They also found that after rehabilitation the deviation improved with the mean of 1.35 degrees. The authors concluded that Subjective visual vertical test would be a useful tool for evaluation of clinical manifestations of unilateral vestibular neuritis.

Chetana and Jayesh (2015) studied 23 subjects with vestibular neuritis and found that 83% had tilting of subjective vertical towards side of lesion. The results showed that the improvement in Subjective visual vertical (SVV) tilt correlated very well with the improvement of symptoms in their patients. The authors concluded that static SVV has a potential use in measuring compensation, prognosis and recovery in vestibular neuritis. .

*2.1.4 Sudden sensorineural hearing loss*

Vibert, Häusler, Safran and Koerner (1995) studied a female patient who was suffering from acute right peripheral cochleovestibular loss using SVV test and observed that tilt of the static visual vertical was directed to the side of the lesion. The author concluded that the tilt of the static visual vertical was a sign of a sudden idiopathic peripheral vestibular loss.

Ogawa et al. (2012) examined vestibular and balance function in 65 patients with sudden sensorineural hearing loss using subjective visual vertical (SVV) perception and vestibular evoked potentials. The authors reported that 23% of the participants showed abnormal SVV and 36% showed abnormal VEMP results. The authors speculated that the superior vestibular nerve function affects the tilt of SVV.

Kim, Na, Park and Shin (2013) compared the static vestibular imbalance between sudden sensorineural hearing loss (SSNHL) with vertigo and vestibular neuritis patients during the acute stage of the disease using subjective visual vertical (SVV) test. The results showed that abnormal SVV was observed in 10% of SSNHL with vertigo and 78% of vestibular neuritis patients. The author concluded that abnormal SVV are less frequently encountered in individuals with SSNHL with vertigo.

*2.1.5 Viral labyrinthitis*

Vibert and Safran (1999) measured Subjective visual vertical (SVV) in individuals suffering from viral labyrinthitis after surgical correction using binocular test and monocular test. The authors found that SVV is tilted in individuals with labyrinthitis and concluded that otolith function isaffected in individuals suffering from viral labyrinthitis.

*2.1.6 Sensorineural hearing loss*

Gavin, Hwang, Cushing and Lin (2016) studied 12 subjects with severe to profound hearing loss, in pre and post cochlear implantation period using subjective visual vertical test (SVV). The authors found that many subjects had deviated SVV at pre-operative and post-operative assessments. However, there were no statistically significant change in pre-operative and post-operative SVV test results. Thus, the authors concluded that cochlear implantation did not influence vestibular or balance function.

Gnanasegaram et al. (2016) studied the abnormalities in perception of the vertical plane using static visual vertical test (SVV) in 53 children with sensorineural hearing loss

(SNHL) and aimed to determine whether such abnormalities could be resolved with stimulation from the CI. The results showed that abnormal SVV in nearly half of the participants with CIs in the direction of their deficit. However, after stimulation by CI the abnormal deviation shifted towards the centre. Thus, the authors suggested that CI stimulation plays a role beyond the auditory system, in particular, for improving vestibular/balance function

## 2.2 Clinical applications of vestibular evoked myogenic potentials on peripheral vestibular disorders:

### *2.2.1 Meneire's disease (MD)*

Murofushi, Nakahara, Yoshimura and Tsuda (2011) studied 20 subjects with unilateral definite Meneire's disease using oVEMP and cVEMP to air-conducted 500 Hz tone bursts at 125 dBSPL. Among the 20 patients, 9 showed abnormal ACS oVEMPs after stimulation of the affected side. Eight of these patients showed absence of ACS oVEMP, and one showed decreased amplitudes. Thus, the authors concluded that oVEMP in response to ACS predominantly reflects utricular functions while ACS cVEMP reflects saccular functions.

Egami et al. (2013) studied the sensitivity and specificity of vestibular evoked myogenic potentials (VEMPs) in comparison with caloric test in diagnosing Meniere's disease (MD). They recorded VEMP in response to clicks and short tone burst stimulation and caloric test in 114 individuals with Meniere's disease and found that the sensitivity and specificity of VEMPs were 50% and 48.9% while those of the caloric test were 37.7% and 51.2% respectively. Thus, the authors concluded that the combine use of VEMP and caloric test increased the sensitivity to 65.8% for detection of vestibular impairment in individuals with Meniere's disease. Vibert, Häusler, Safran and Koerner (1995) studied a female patient who was suffering from acute right peripheral cochleovestibular loss using SVV test and observed that tilt of the static visual vertical was directed to the side of the lesion.

Sinha et al. (2015) recorded cVEMP and oVEMP in 25 contralateral ears of Meniere's disease. Both cVEMP and oVEMP was absent in 5 of the ears, cVEMP was absent and oVEMP was present in 13 ears, cVEMP was present and oVEMP was absent in 1 ear, whereas both cVEMP and oVEMP were present in 6 ears in individuals with Meniere's disease. The authors concluded that the combination of cVEMP and oVEMP provides valuable information regarding localization of hydrops in individuals with Meniere's disease.

Singh and Barman (2016) investigated the feasibility of frequency tuning of oVEMP in discriminating Meniere's disease from benign paroxysmal positional vertigo (BPPV) in 36 individuals, each with unilateral Meniere's disease and unilateral BPPV. The results showed that a significantly higher proportion of affected ears with Meniere's disease showed the frequency tuning at 1000 Hz than the comparison group as well as ears with BPPV. The authors concluded that shift in frequency tuning is an efficient parameter for not only discriminating Meniere's disease from healthy individuals but also distinguishing it from BPPV and recommended frequency tuning as a test parameter of oVEMP for identification of Meniere's disease.

Singh and Barman (2016) investigated the utility of FAR of oVEMP in identifying Meniere's disease and tried to find out an optimum frequency pair for its diagnosis. They recorded oVEMPs using tone bursts of 500, 750, 1000, and 1500 Hz from 36 individuals with unilateral definite Meniere's disease in the age range of 15 to 50 years. The results revealed significantly higher FAR in the Meniere's disease group than the healthy controls for all the frequency pairs. The authors concluded that high sensitivity and specificity, coupled with considerably lowered test duration when using only two frequencies, makes the use of FAR a more attractive prerogative, with 1000/500 as the frequency pair of choice.

*2.2.2 Vestibular neuritis*

Curthoys et al., (2011) recorded oVEMP to 500 Hz air conduction stimulation and 500Hz bone conduction stimulation in 10 individuals with superior vestibular neuritis and found that its amplitude was reduced or absent results in all 10 cases of superior vestibular neuritis individuals with normal function of saccular and inferior vestibular nerve and concluded that oVEMP to air conduction stimulation and bone conduction stimulation is predominantly mediated by utricle and superior vestibular nerve.

oVEMP is reported to be absent in cases with vestibular neuritis as it affects the superior vestibular nerve more of often than the inferior vestibular nerve. Murofushi et. al. (2011) studied 6 patients with unilateral vestibular neuritis (VN) using oVEMP and cVEMP to air-conducted 500 Hz tone bursts at 125 dBSPL. They found that all the six patients with unilateral VN showed abnormal ACS oVEMP responses after stimulation on the affected side. Five patients showed absence of oVEMP and one showed prolonged nI latency. The author concluded that ACS oVEMP predominantly reflect utricular function.

Chiarovano et al., (2011) studied 12 individuals with vestibular neuritis at the acute stage using air conduction cVEMP and oVEMP using 500Hz tone burst and found that there was no difference in terms of latencies between the affected and the intact side. However, there was a greater than 50% dissociation between cVEMP and oVEMP results. Thus, the authors concluded that cVEMP along with oVEMP can be used to find whether vestibular neuritis has affected or spared the inferior vestibular nerve.

Shin et al. (2012) have recently reported the changes occurring for oVEMPs and cervical VEMPs (cVEMPs) evoked by air conducted sound (ACS) in vestibular neuritis (VN) classified as affecting the superior, inferior or both divisions of the vestibular nerve.

They found oVEMPs affected in superior VN while cVEMPS were apparently normal, with the converse for inferior VN. They concluded that oVEMPs were the result of utricular activation.

*2.2.3 Idiopathic hearing loss*

Zhang et al. (2013) studied the function of the otolithic end organs and their input pathways in 40 subjects with sudden sensorineural hearing loss (SSHL). The authors couldn't find any significant statistical difference in all oVEMP and cVEMP parameters among groups. The authors concluded that the otolithic vestibular end organs and their input pathways could be damaged in SSHL patients and such damages could be monitored objectively by cVEMP and oVEMP examinations.

Fujimoto et al (2015) investigated the extent of vestibular lesions in 25 cases with idiopathic sudden hearing loss (ISHL) with vertigo using oVEMP. The results showed abnormal oVEMP findings on the affected side in 25 participants. The authors concluded that the vestibular end organs close to the cochlea tended to be preferentially affected.

Nui et al. (2015) assessed 149 individuals with sudden sensorineural hearing loss, with or without vertigo, using cervical vestibular evoked myogenic potentials (cVEMP), ocular vestibular myogenic potentials (oVEMP) and caloric test. The VEMP was carried out through air conduction of 500Hz tone-burst of rise and fall time of 1ms and plateau of 2ms at 131 dBSPL. The authors reported that oVEMP was found to be abnormal in 56% and 70% of the individuals with and without vertigo.

Jing et al (2017) evaluated 35 subjects with idiopathic sudden sensorineural hearing loss with cervical and ocular vestibular evoked myogenic potentials and caloric test. The authors found the highest rate of abnormal responses in oVEMP followed by caloric test and cVEMP in subjects with vertigo and without vertigo. The authors concluded that the vestibular damage of sudden deafness with vertigo was more likely involved with saccule and inferior vestibular nerve, closer to the nerve terminal.

*2.2.4 Semi-circular canal dehiscence*

Zuniga et al (2013) attempted to determine whether cervical vestibular evoked myogenic potential (cVEMP) thresholds or ocular VEMP amplitudes are more sensitive and specific in the diagnosis of superior semi-circular canal dehiscence syndrome (SCDS). They studied 29 patients with SCDS and age matched controls. cVEMP threshold results showed sensitivity and specificity ranging from 80–100% for the diagnosis of SCDS. In contrast, oVEMP amplitudes demonstrated sensitivity and specificity >90%. The author concluded that oVEMP are more sensitive in diagnosis of of superior semi-circular canal dehiscence syndrome.

*2.2.5 Benign paroxysmal positional vertigo*

Benign paroxysmal positional vertigo (BPPV) is a unilateral peripheral vestibular pathology characterized by brief episodes of vertigo which are often precipitated by head motion in the vertical or horizontal planes (McClure 1985; Epley 1992). In BPPV, the degenerative process that affects the macula of the utricle and causes detachment of the otoliths might also affect the macula of the saccule. It is a disease with one of the highest prevalence among the otological disorders and is the most common cause of vertigo after head injury (Davies & Luxon 1995; Hornibrook 2011).

Nakahara et al. (2013) recorded oVEMP and cVEMP in individuals with BPPV. Authors found that oVEMP response was abnormal in affected side whereas no significant difference was found between individuals with BPPV and control group for cVEMP response. Thus, the author concluded that there was no association between oVEMP, cVEMP and caloric tests in the diagnosis of individuals with BPPV.

Lee et al (2013) recorded oVEMP and cVEMP in 16 individuals with BPPV. The results showed that 31.3% of individuals with BPPV have abnormal cVEMP and 25% of individuals with BPPV have abnormal oVEMP response. Thus, the author concluded that VEMP is an important tool to diagnose otolith dysfunction in BPPV.

Nakahara, Yoshimura, Tsuda & Murofushi (2013) evaluated the utricular and saccular function using oVEMP and cVEMP in 12 patients with pBPPV using 500 Hz tone burst at 125 dB SPL. The results showed that most of the patients with pBPPV showed abnormal responses in oVEMPs by stimulation on their affected side than the controls. The author concluded that the urticular function in pBPPV patients was highly damaged.

Xu et al. (2016) evaluated the difference in cervical and ocular VEMPs between patients with BPPV and normal controls, as well as between patients with recurrent and non-recurrent BPPV. Abnormal oVEMP responses were detected in 17 of 30 (56.7 %) subjects in BPPV group. Also more patients with BPPV showed abnormal responses in oVEMPs as compared to the controls. The authors concluded that oVEMPs were more often abnormal in BPPV patients as compared to cVEMPs, suggesting that utricular dysfunction may be more common than saccular dysfunction. Therefore, assessment of c/oVEMPs in BPPV patients may therefore be of prognostic value in predicting likelihood of BPPV recurrence.

*2.2.6 Labrynthitis*

Vestibular neuritis predominantly affects the superior branch of the vestibular nerve, resulting in vertigo. Acute viral labyrinthitis occurs when an infection affects both vestibulo-cochlear nerve and labyrinth, resulting in hearing changes as well as vertigo.

Moon and Lee (2012) evaluated if there is a difference of cervical vestibular evoked myogenic potentials (cVEMP) and ocular VEMP (oVEMP) in patients with vestibular neuritis and acute viral labyrinthitis. cVEMP and oVEMP tests using 500-Hz tone-burst stimuli were performed. Abnormal oVEMP responses were detected in 9 patients (90%) with vestibular neuritis and 5 (100%) patients with labyrinthitis. Abnormal cVEMP responses were detected in 2 (20%) patients with vestibular neuritis and 5 (100%) patients with labyrinthitis. The author concluded that the response of cVEMP and oVEMP between patients with vestibular neuritis and acute viral labyrinthitis is different.

*2.2.7 Auditory neuropathy spectrum disorder*

Sinha, Shankar and Sharanya (2013) administered cervical vestibular evoked myogenic potentials (cVEMPs) and ocular vestibular evoked myogenic potentials (oVEMPs) using 500Hz tone burst stimuli at 95dBnHL on 11 participants with auditory neuropathy spectrum disorder. The results showed that oVEMP was absent in 100% of the participants (100%) whereas cVEMPs were absent in 20 ears out of 22 ears tested (90.90%) indicating a high incidence of vestibular involvement in individuals with auditory neuropathy spectrum disorders. The author concluded that there is a need to necessitate the inclusion of vestibular tests in the test battery used to assess individuals with auditory neuropathy spectrum disorder.

Singh, Sinha and Barman (2016) aimed at investigating otolith modulated neural function in individuals with ANSD. cVEMP and oVEMP were elicited by 500-Hz tone bursts from 31 individuals with ANSD and 31 age- and gender-matched healthy controls. Results showed that the response prevalence was less than 20% for both potentials. The present responses were characterized by significant prolongation of later peaks and inter-peak latency intervals and significantly reduced amplitudes compared to the controls. The author concluded that a detailed vestibular evaluation, in addition to the auditory system assessment, is necessary in ANSD.

*2.2.8 Sensorineural hearing loss*

Bansal, Sahni and Sinha (2013) administered oVEMP and cVEMP on 20 individuals with severe to profound hearing loss and found that cVEMP and oVEMP were present in 100% and 66% of the subjects respectively. Therefore, the authors suggested more utricular dysfunction is noted in individuals with severe to profound hearing loss than saccular dysfunction.

Kalaiah et al (2014) studied the vestibular functions in 22 individuals with sensorineural hearing loss of various degrees of severity (mild, moderate and moderately severe). The result revealed that the mild hearing loss had reduced VEMP responses, absent responses in right ear and present responses in left ears (71%) in moderate degree of hearing loss, present VEMP response in 16.6% in moderately severe degree of hearing loss. They also found that across the degree of hearing loss no significant relationship was found.

Xu et al (2015) studied the profile of ocular and cervical vestibular-evoked myogenic potential (oVEMP and cVEMP) in 23 children with profound sensorineural hearing loss (PSHL). The response rates of oVEMP and cVEMP in patients with PSHL were 58.1% and 61.9% respectively and significant elevated thresholds and decreased amplitudes in VEMPs were noted. The authors also concluded that VEMPs have special value in observation of the hidden loss of otolithic function, and could be an important vestibular assessment method for children with PSHL.

Xu et al (2016) studied the profiles of ocular and cervical vestibular-evoked myogenic potentials in 29 patients with profound sensorineural hearing loss (PSHL) using ACS-evoked oVEMPs and cVEMPs. The results showed that oVEMPs had significantly higher threshold and smaller amplitude than cVEMPs. The authors concluded that the utricular and saccular dysfunction that are hidden in patients with PSHL can be observed in oVEMPs and cVEMPs and that otolithic function should receive attention in the diagnosis and treatment of PSHL.

# CHAPTER III

# METHOD

The present study was conducted with aim of assessing the utricular function using ocular vestibular evoked myogenic potentials (oVEMP) and subjective visual vertical test (SVV) in individuals with various degree of sensorineural hearing loss. To meet the aim of the study the participants were divided in to two groups.

*Group I:*

28 participants (12 males and 18 females) within the age range of 18-40 years were considered for this study. Out of 28 participants, 9 participants had minimal to mild sensorineural hearing loss, 9 participants had moderate to moderately severe sensorineural hearing loss and 10 participants had severe to profound sensorineural hearing loss.

**Selection criteria for participants of group I:**

1. All the participants had bilateral minimal to profound symmetrical sensorineural hearing loss.
2. Participants had negative history of middle ear problems (ear pain, ear discharge) and conductive hearing loss.
3. None of the participants had any indication of retro cochlear pathology.
4. Participants had no definite history of any vestibular disease (eg: Labyrinthitis, vestibular neuritis, Meniere's disease).
5. Participants did not have hypertension and diabetes and other neurological problems.

*Group II*:

28 Participants with normal hearing (12 males & 18 females) within the age range of 18-40 years participated in the study.

**Selection criteria for participants of group II:**

1. All the participants had normal hearing sensitivity in the frequency range of 250-8000Hz in both ears.
2. Participants did not have any signs and symptoms or history of any middle ear pathology.
3. Participants did not have any history/presence of vestibular symptoms/disorder.
4. None of the participants had history/presence of hypertension and diabetes and any other neurological problems.
5. None of the participants showed any evidence of any retrocochlear pathology.

*Testing environment:*

All the tests were conducted in an acoustically treated room with the permissible noise level as per ANSI S 3.1 (1991) standards.

*Test Equipment:*

1. Calibrated GSI-61 audiometer (VIASYS Healthcare Inc, Conshohocken, Pa) with TDH-39 headphone encased in MX-41/AR (Telephonics, Farmingdale, NY, USA) supra-aural cushion with earphones (Northeastern Technologies, Glen Cove, NY) was utilized for estimation of air conduction pure tone thresholds.
2. Bone conduction threshold was estimated using Radio ear B-71 bone vibrator (Radioear, KIMMETRICS, Smithsburg, MD, USA).
3. Middle ear status was evaluated using a calibrated Grason-Stadler Tympstar (GSI) middle ear analyzer (version 2.0, GSI VIASYS Healthcare, WI, USA)
4. Intelligent Hearing System version 4.3.02 (Intelligent Hearing System, Florida, USA), with ER-3A Insert ear phone (Etymotic Research, Inc., Elk Grove Village, IL, USA) was used to record auditory brainstem response.
5. Bio-Logic Navigator Pro System (Natus Medical Incorporated, San Carlos, CA, USA) was used to record vestibular evoked myogenic potentials (VEMP)

6. Bio Med Jena GmbH Biomedizinische Technik (BioMed Jena GmbH Biomedizinische Technik, Germany) was be used for recording subjective visual vertical test.

*Procedure*

1. *Case history*: The case history included questions pertaining to presence or absence of vestibular symptoms. The details regarding the vestibular symptoms such as vertigo, imbalance, headache, nausea/ vomiting and visual problems (Nystagmus/blurring of vision) were recorded from all participants of the study. Questions regarding presence of any middle ear pathology and medication taken if any was taken from all the participants.
2. *Pure-tone audiometry*: Hearing thresholds were obtained using the modified version of Hughson and Westlake procedure (Carhart, 1959) at octave frequencies between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction.
3. *Immittance Audiometry*: Tympanograms were obtained with 226Hz probe frequency for both ears followed by acoustic reflex thresholds estimation of both ipsilateral and contralateral for 500, 1000, 2000 and 4000Hz stimulus.
4. *Uncomfortable loudness level (UCL):* UCL for speech was determined using ascending method for all the subjects. UCL was determined to see if the subjects have intolerance to loud sound which was used during VEMP testing.
5. *Auditory brainstem responses (ABR):* ABR was recorded using clicks of 100 µs duration, presented at 11.1/s repetition rate. The inverting electrode was placed on the test ear, the non-inverting on the upper forehead and ground electrode on the contralateral mastoid and responses were recorded in rarefaction polarity. The

obtained responses were analysed in 12msec time window and the responses were filtered between 100 Hz-3000 Hz.

6. *Ocular vestibular evoked myogenic potentials*: Electrode placement site was prepared using a skin preparation gel. Surface disc (AgCl) electrodes were used for recording. Using a single-channel surface electrode montage, the inverting electrode was placed 1cm inferior to the lower eyelid and the non-inverting electrode was placed 1cm below the inverting electrode. Absolute electrode impedances were maintained below 5 kΩ and inter-electrode impedances was maintained below 2 kΩ. Electromyographic potentials were evoked with a 500 Hz tone burst (tone burst stimuli of 500 Hz was used as the 500 Hz tone burst stimulus gives better amplitude of the oVEMPs), Blackman-windowed tone burst presented at a rate of 5.1 Hz at 125dBSPL (rarefaction polarity) for 200 sweeps presented via insert ER3A earphones (Etymotic Research, Inc.) to individual ears while the patient looked upward (30 degrees). The ocular VEMP was recorded contralaterally i.e the electrode was placed on the left side when stimulus was presented to the right ear or vice versa. For the ease of reading, the results in further section has been described with reference to the stimulus ear. The response was analyzed for 50ms post stimulus period. A pre-stimulus period of 10ms was utilized to record background electrical activity. Electromyograms thus obtained were bandpass filtered (1–1000 Hz), and amplified 5000 times. To ensure the reliable responses, recordings were done twice.
7. *Subjective visual vertical test*: The subject was seated upright in a chair, and head supports were used to maintain a vertical position of the head. The subject was made to wear VNG goggles which had a small screen on which a luminous line was projected (Figure 3.4). The subjective visual vertical was recorded at static (0 degree) and head tilted position. (30 degrees) at the right and left side. Figure 3.1,

3.2 and 3.3 shows the subject wearing goggles at zero degree, thirty degree right and thirty degree left head positions respectively. The luminous line appeared randomly in the negative angle (counterclockwise rotation) and in the positive angle (clockwise rotation). Participants were instructed to align the luminous line to the gravitational vertical using a joystick. The value/response was confirmed by pressing a button below the joy stick. Every adjustment was repeated five times at both static and tilted angles. The average of the five trials were taken as the subjective visual vertical.

*Figure 3.1*: Subject at zero degree head position wearing binocular VNG goggles.

*Figure 3.2*: Subject at right thirty-degree head position wearing binocular VNG goggles.

*Figure 3.3*: Subject at left thirty-degree head position wearing binocular VNG goggles.

*Figure 3.4*: Goggles showing the luminous light

**DATA ANALYSIS**

1. Ocular VEMP:

    a. The latency of N1 Peak for both the groups

    b. The latency of P1 Peak for both the groups

    c. The latency of N2 peak for both the groups

    d. Amplitude complex of N1-P1 & P1-N2 for both the groups

2. Subjective visual vertical test

    Average of perceptual vertical angles is calculated at static (0 degree) and (30 degree) of head movement.

# CHAPTER IV

# RESULTS

The present study was conducted with an aim of assessing the functioning of utricle using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with various degrees of sensorineural hearing loss. 28 participants with mild to profound sensorineural hearing loss and 28 participants with normal hearing were employed in the study. To analyse the data, Statistical Package for the Social Science (SPSS) version 20 was used. The results of the data are presented in the following sub headings:

4.1 Ocular vestibular evoked myogenic potentials findings.

4.2 Subjective visual vertical test findings.

4.3 Correlation between ocular VEMP and SVV test findings in individuals with various degree of sensorineural hearing loss.

4.4 Association between degree of hearing loss and ocular VEMP findings.

## 4.1 Ocular vestibular evoked myogenic potentials findings

In the normal hearing group, oVEMP was present in 100% of the participants and in the hearing loss group oVEMP was present in 64% (18 out of 28) of right ears and 67% (19 out of 28) of left ears.

Figure 4.1 shows the representative waveform of presence of oVEMP in normal hearing individual in right ear and left ear. Figure 4.2a shows the representative waveform of presence of oVEMP recorded in individual with minimal to mild sensorineural hearing loss. Figure 4.2b shows the representative waveform of presence of oVEMP in left ear and absence of oVEMP in right ear recorded in individual with minimal to mild sensorineural hearing loss. Figure 4.3a shows the representative waveform of presence of oVEMP recorded in individual with moderate to moderately severe sensorineural hearing loss. Figure 4.3b shows the representative waveform of absence of oVEMP recorded in individual with moderate to moderately severe sensorineural hearing loss. Figure 4.4a shows the representative waveform for presence of oVEMP recorded in individual with severe to profound sensorineural hearing loss. Figure 4.4b shows the representative waveform for absence of oVEMP recorded in individual with severe to profound sensorineural hearing loss.

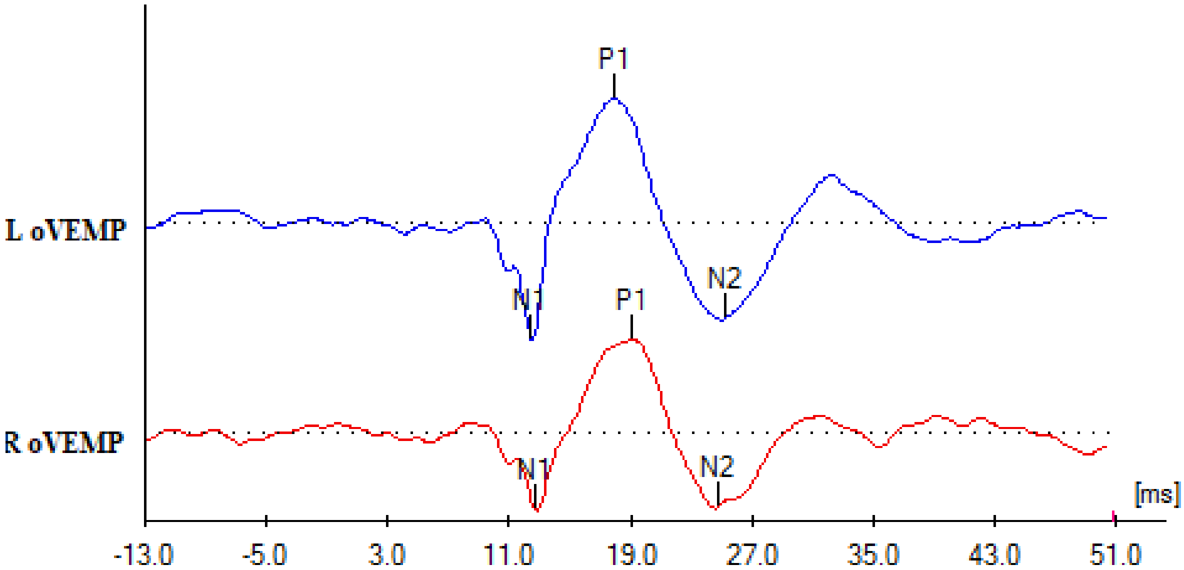


*Figure 4.1*: Representative waveform showing presence of oVEMP in a normal hearing individual in right ear and left ear.

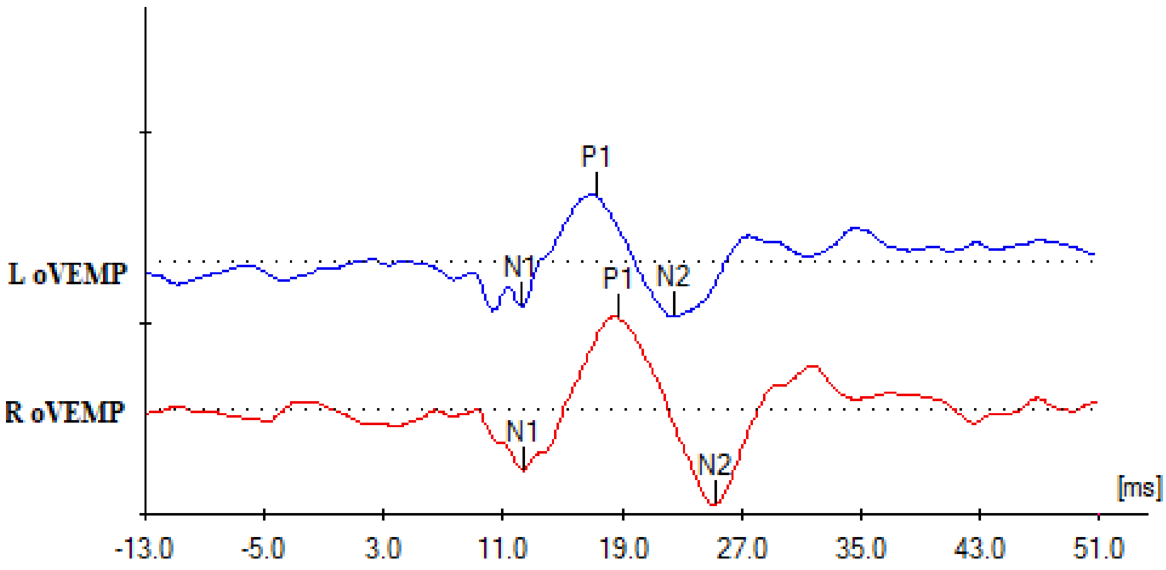


*Figure 4.2a;* Representative waveform showing presence of oVEMP recorded in an individual with minimal to mild sensorineural hearing loss.

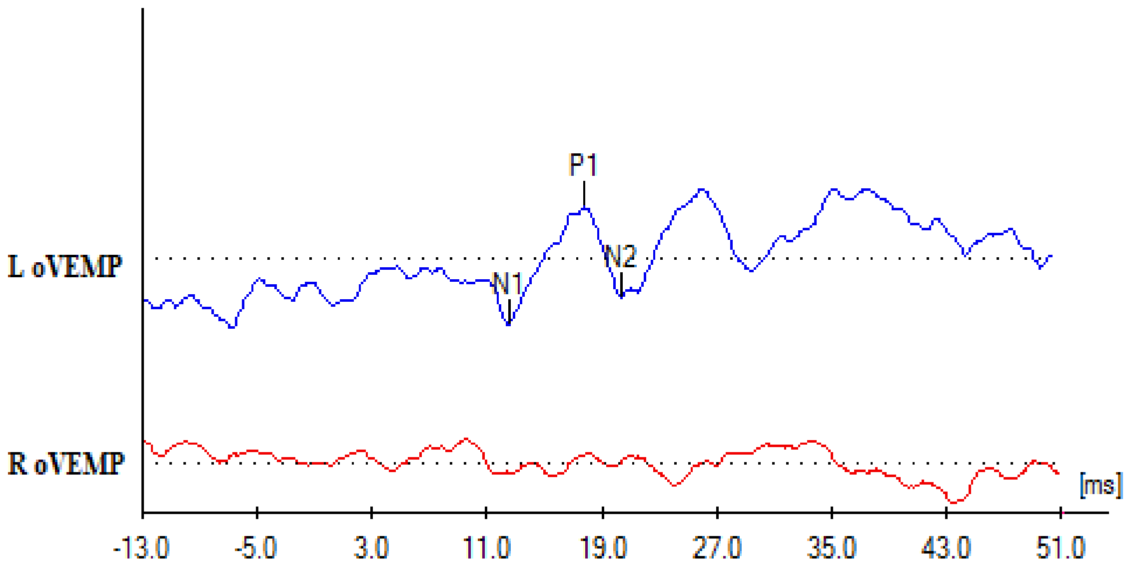


*Figure 4.2b:* Representative waveform showing presence of oVEMP in left ear and absence of oVEMP in right ear recorded in an individual with minimal to mild sensorineural hearing loss

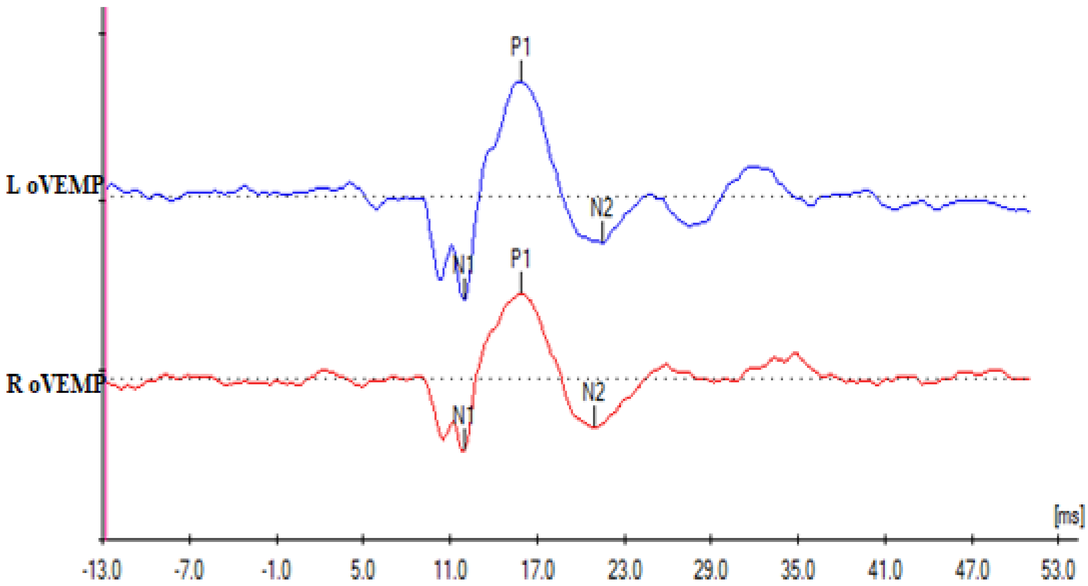


*Figure 4.3a*: Representative waveform showing presence of oVEMP recorded in individual with moderate to moderately severe sensorineural hearing loss.

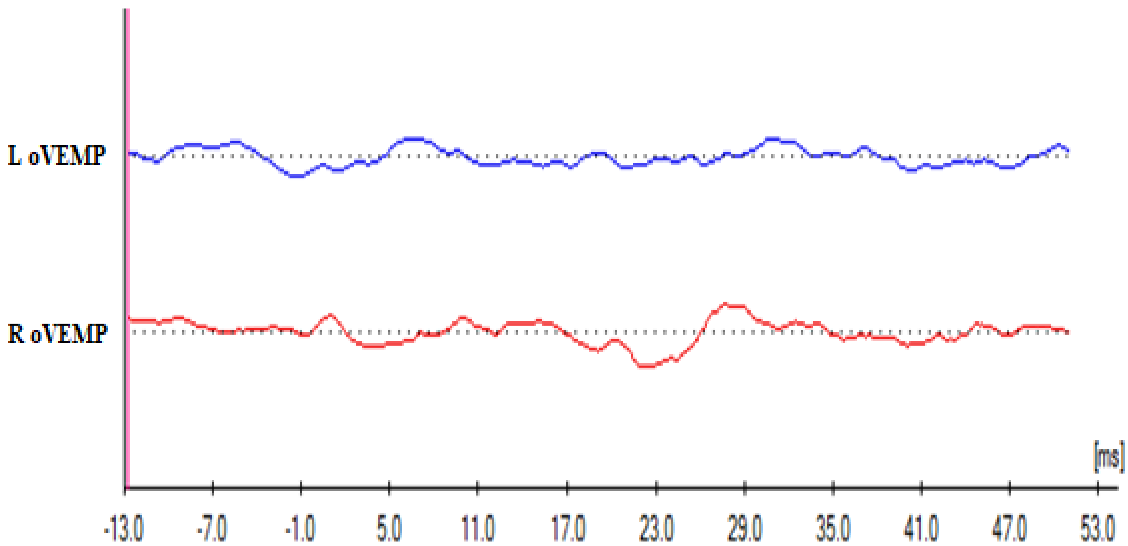


*Figure 4.3b:* Representative waveform showing absent oVEMP recorded in individual with moderate to moderately severe sensorineural hearing loss.

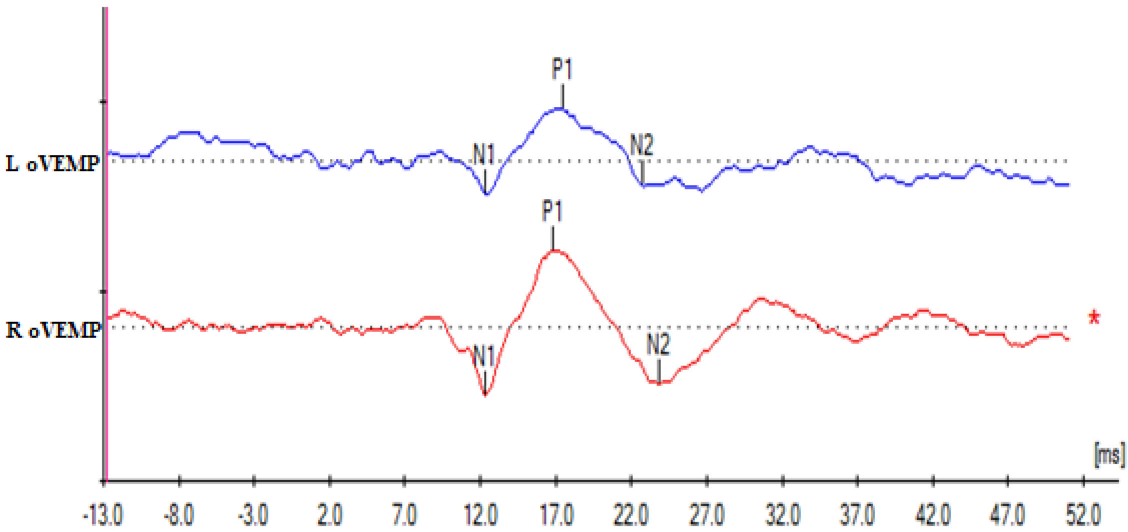


*Figure 4.4a:* Representative waveform showing presence of oVEMP recorded individuals with severe to profound sensorineural hearing loss.

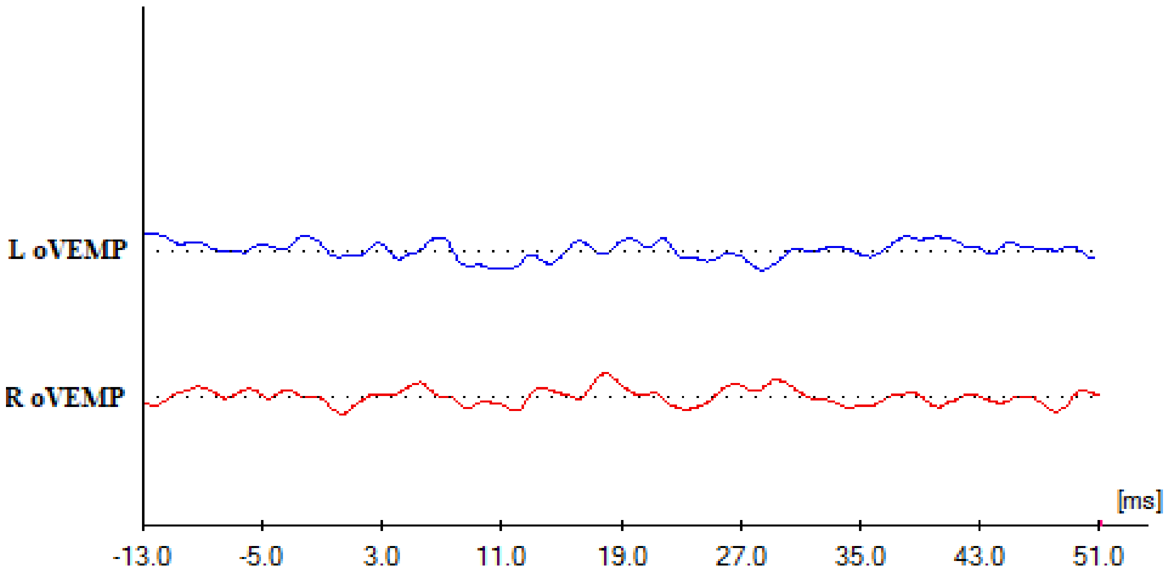


*Figure 4.4b*: Representative waveform showing absent oVEMP recorded in individual with severe to profound sensorineural hearing loss.

Descriptive statistics was done to calculate the mean and standard deviation for the latency and amplitude parameters of oVEMP for both the groups. The mean latency (msec) and the standard deviation for n1 latency, p1 latency, n2 latency and peak to peak amplitude of n1-p1 and p1-n2 for normal hearing group and hearing-impaired group is shown in Table 4.1 and Table 4.2 respectively.

Table 4.1

*Mean and standard deviation for various latency and amplitude parameters of oVEMP in right and left ear in normal hearing individuals.*

| | **Right ear (n=28)** | | **Left ear (n=28)** | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| **n1 Latency (msec)** | 12.30 | 0.69 | 12.09 | 0.74 |
| **p1 Latency (msec)** | 17.33 | 0.83 | 17.13 | 0.91 |
| **n2 Latency (msec)** | 22.10 | 4.32 | 21.41 | 4.67 |
| **n1-p1 amplitude (μV)** | 8.8 | 4.41 | 11.44 | 6.79 |
| **p1-n2 amplitude (μV)** | 13.6 | 11.67 | 10.02 | 4.20 |

Table 4.2

*Mean and standard deviation for various latency and amplitude parameters of oVEMP in right and left ear in hearing impaired individuals.*

| | | **Right ear** | | **Left ear** | |
|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD |
| **Minimal to mild sensorineural hearing loss** | n1 Latency (msec) | 12.55 | 0.67 | 12.08 | 0.42 |
| | p1 Latency (msec) | 17.93 | 1.23 | 18.23 | 1.52 |
| | n2 Latency (msec) | 23.49 | 2.07 | 23.31 | 1.45 |
| | n1p1 amplitude(μV) | 10.37 | 5.39 | 10.96 | 5.55 |

| | | | | | |
|---|---|---|---|---|---|
| | p1n2 amplitude(μV) | 10.21 | 6.31 | 9.89 | 7.18 |
| **Moderate to moderately severe sensorineural hearing loss** | n1 Latency (msec) | 14.62 | 3.51 | 12.76 | 1.29 |
| | p1 Latency (msec) | 19.10 | 3.23 | 17.34 | 1.87 |
| | n2 Latency (msec) | 24.67 | 3.15 | 22.55 | 1.90 |
| | n1p1 amplitude(μV) | 5.96 | 6.06 | 9.85 | 8.23 |
| | p1n2 amplitude(μV) | 5.92 | 4.66 | 7.87 | 5.87 |
| **Severe to profound sensorineural hearing loss** | n1 Latency (msec) | 11.99 | 0.79 | 11.50 | 0.73 |
| | p1 Latency (msec) | 16.95 | 1.12 | 16.29 | 1.04 |
| | n2 Latency (msec) | 21.90 | 1.76 | 21.57 | 0.951 |
| | n1p1 amplitude(μV) | 8.16 | 6.11 | 16.46 | 6.62 |
| | p1n2 amplitude(μV) | 6.58 | 4.44 | 12.29 | 5.05 |

It can be seen from Table-4.1 and Table 4.2 that mean latencies of n1, p1 and n2 peak of oVEMP potential of individuals with normal hearing is almost similar to individual with hearing impairment except for the right ear of moderate to moderately severe sensorineural hearing loss group, where the latencies are slightly longer. However, the mean amplitude complex of n1-p1 and p1-n2 in individual with normal hearing are larger than individual with hearing loss.

The obtained data was tested for normality distribution. Shapiro-Wilk test of normality was administered and it was found that the data had normal distribution ($p>0.05$). Therefore, first the parametric statistics was done.

To understand the ear differences for different parameters of oVEMP, paired-sample t-test was conducted to find out the significant difference between right and left ear for both normal hearing group and hearing impaired group. The results of the paired sample t test are given in Table 4.3 and Table 4.4 for normal-hearing and hearing-impaired group respectively.

Table 4.3

*Comparison of parameters of oVEMP between right and left ear in normal hearing group.*

| | **t** | **Sig. (2-tailed)** |
|---|---|---|
| **n1 latency** | 1.10 | 0.27 |
| **p1 latency** | 0.87 | 0.39 |
| **n2 latency** | 0.66 | 0.51 |
| **n1-p1 amplitude** | 1.75 | 0.09 |
| **p1-n2 amplitude** | 1.57 | 0.12 |

Table 4.4

*Comparison of parameters of oVEMP between right and left ear in hearing impaired group.*

| | **t** | **Sig. (2-tailed)** |
|---|---|---|
| **n1 latency** | 1.91 | 0.07 |
| **p1 latency** | 1.67 | 0.11 |
| **n2 latency** | 1.98 | 0.06 |
| **n1-p1 amplitude** | 1.95 | 0.06 |
| **p1-n2 amplitude** | 0.99 | 0.33 |

It can be seen from Table 4.3 and Table 4.4 that there was no significant difference in the mean n1, p1, n2 latencies and n1-p1 and p1-n2 amplitude complex of right and left ear ($p>0.05$) for both the groups.

Since the paired sample t-test revealed no significant differences for any of the oVEMP parameters for the two ears, the data of the two ears for both the groups were combined. Descriptive statistics was done to calculate the mean and standard deviation of overall combined data for latency and amplitude of oVEMP in normal-hearing and hearing-impaired group. The values of mean and standard deviation for n1 latency, p1 latency, n2 latency, n1-p1 amplitude complex and p1-n2 amplitude complex of normal-hearing and hearing-impaired group is shown in the Table 4.5

Table 4.5

*Mean and standard deviation for oVEMP parameters of individual with normal hearing and individual with various degrees of hearing loss.*

| | **Groups** | **N (number of ears)** | **Mean** | **SD** |
|---|---|---|---|---|
| **n1 peak (msec)** | Normal hearing | 56 | 12.20 | 0.72 |
| | Minimal to mild sensorineural hearing loss | 16 | 12.31 | 0.59 |
| | Moderate to moderately severe sensorineural hearing loss | 11 | 13.60 | 2.59 |
| | Severe to profound sensorineural hearing loss | 10 | 11.75 | 0.76 |
| **p1 peak (msec)** | Normal hearing | 56 | 17.23 | 0.87 |
| | Minimal to mild sensorineural hearing loss | 16 | 18.08 | 1.34 |
| | Moderate to moderately severe sensorineural hearing loss | 11 | 18.14 | 2.60 |

| | | | | |
|---|---|---|---|---|
| | Severe to profound sensorineural hearing loss | 10 | 16.62 | 1.07 |
| **n2 peak (msec)** | Normal hearing | 56 | 21.76 | 4.47 |
| | Minimal to mild sensorineural hearing loss | 16 | 23.40 | 1.73 |
| | Moderate to moderately severe sensorineural hearing loss | 11 | 23.51 | 2.65 |
| | Severe to profound sensorineural hearing loss | 10 | 21.73 | 1.34 |
| **n1-p1 amplitude complex (µV)** | Normal hearing | 56 | 10.12 | 5.83 |
| | Minimal to mild sensorineural hearing loss | 16 | 10.66 | 5.29 |
| | Moderate to moderately severe sensorineural hearing loss | 11 | 8.08 | 7.26 |
| | Severe to profound sensorineural hearing loss | 10 | 12.31 | 7.43 |
| **p1-n2 amplitude complex (µV)** | Normal hearing | 56 | 11.82 | 8.88 |
| | Minimal to mild sensorineural hearing loss | 16 | 10.05 | 6.53 |
| | Moderate to moderately severe sensorineural hearing loss | 11 | 6.98 | 5.19 |
| | Severe to profound sensorineural hearing loss | 10 | 9.43 | 5.39 |

It can be seen from Table-4.5 that mean latencies of n1, p1 and n2 of oVEMP potential of individuals with normal hearing is almost similar to individual with hearing impairment. However, the mean amplitude complex of n1-p1 and p1-n2 in individual with normal hearing are larger than individual with hearing loss. Among the hearing-impaired group, it was noted that the mean n2 latency of the moderate to moderately severe group were longest. The same can be seen in figure 4.5. The amplitude of n1-p1 were the largest in the severe to profound hearing-impaired group which can be seen form the figure 4.6.

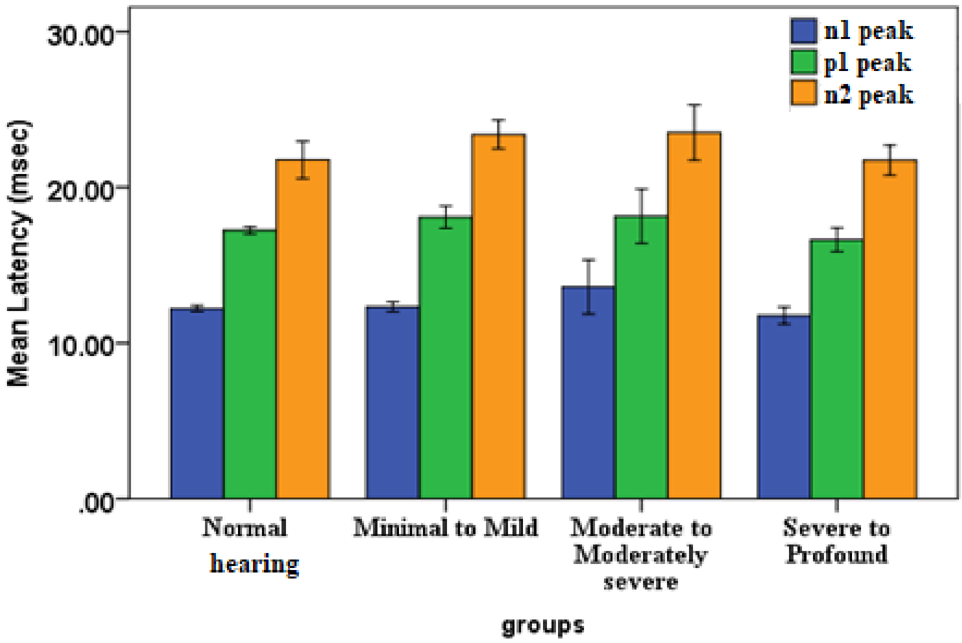


*Figure 4.5:* Bar graph showing the mean n1, p1 and n2 latencies for normal hearing individuals and individuals with various degrees of hearing loss.

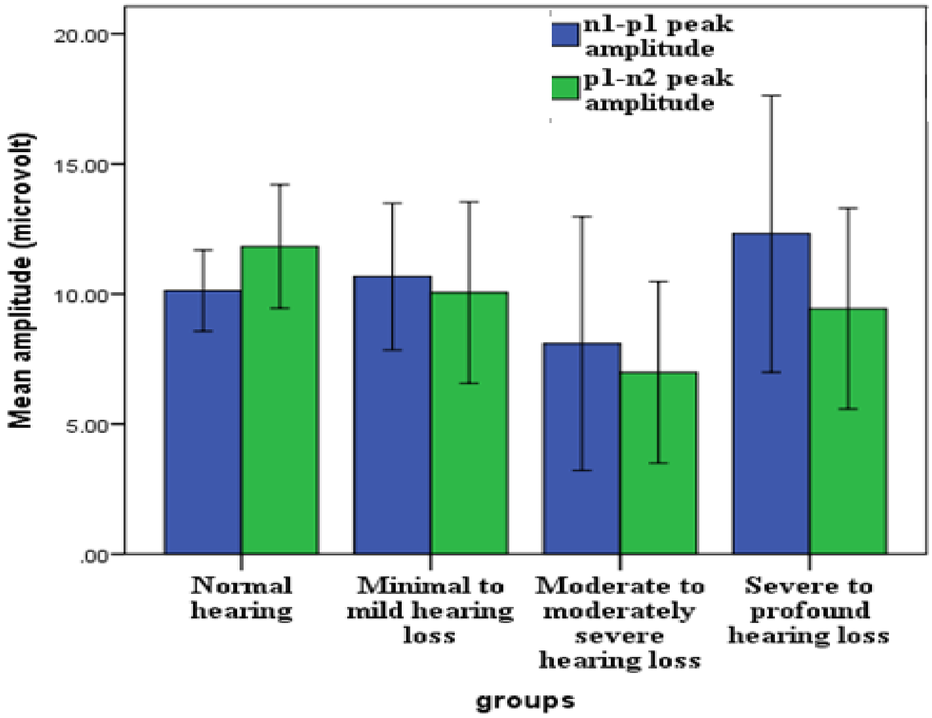


*Figure 4.6*: Bar graph showing the mean n1p1 and p1n2 amplitudes for normal hearing individuals and individuals with various degrees of hearing loss.

Further to compare significant differences in the mean values of oVEMP parameters between the normal hearing and hearing-impaired individuals the multivariate analysis of variance (MANOVA) was done. Multivariate analysis of variance revealed a significant main effect in the latencies of n1 [F (3,89) = 6.17, p<0.05] and p1 [F (3,89) = 4.24, p<0.05]. However, there was no significant main effect for n2 latency [F (3,89) = 1.33, p>0.05] and the amplitude complexes of n1-p1 [F (3,89) = 0.87, p>0.05] and p1-n2 [F (3,89) = 1.32, p>0.05].

In order to determine particularly which of the four groups a significant difference exists, Duncan's post hoc analysis was done. For the n1 latency the moderate to moderately severe hearing loss group differed significantly from the rest of the hearing-impaired groups and the normal hearing group (p<0.05). For the p1 latency, the profound hearing loss group and the normal hearing group differed significantly from the other two hearing impaired groups (p<0.05). For the n2 latency, the mean did not differ significantly across the four groups (p>0.05).

Since, there was uneven sample size among the three groups taken for the study due to the presence and absence of responses, Kruskal-Wallis test was done to cross check the results of the MANOVA. The results of the Kruskal-Wallis also revealed a significant difference in the latency value of p1 peak between the groups (p<0.05). There was no significant difference in the other parameters of oVEMP across the groups (p>0.05). Table 4.6 shows Chi- square values along with significant level across the groups.

Table 4.6

*Chi square values along with significant level across the groups.*

| | **n1 peak** | **p1 peak** | **n2 peak** | **n1-p1 amplitude** | **p1-n2 amplitude** |
|---|---|---|---|---|---|
| **Chi-square** | 6.53 | 10.49 | 5.75 | 2.98 | 6.77 |
| **Degrees of freedom** | 3 | 3 | 3 | 3 | 3 |
| **Significance level** | 0.08 | 0.01 | 0.12 | 0.39 | 0.08 |

Further to understand the significant difference in the mean latency and amplitude of different parameters for the combined data between the normal hearing and hearing-impaired groups and across the hearing-impaired groups, Mann-Whitney U Test was done. Mann-Whitney U test showed a significant difference for p1 peak latency [Z=2.94, p<0.05] for the normal hearing and minimal to mild hearing loss group. There was no significant difference for n1 peak latency [Z=0.36, p>0.05], for n2 peak latency [Z=1.83, p>0.05] and the amplitude complexes of n1-p1 [Z=0.88, p>0.05] and p1-n2 [Z=1.16, p>0.05] between these groups.

Between the normal hearing and moderate to moderately severe hearing loss group, the Mann-Whitney U test revealed significant difference for the n1 peak latency [Z=2.09, p<0.05]and for amplitude complex of p1-n2 [Z=2.42, p<0.05] and there was no significant difference for p1 peak latency [Z=0.59, p>0.05], for n2 peak latency [Z=1.08, p>0.05] and the amplitude complex of n1-p1 [Z=1.27, p>0.05].

Between the normal hearing and severe to profound hearing loss group, the Mann-Whitney U test revealed no significant difference for the n1 peak latency [Z=1.34, p>0.05], for p1 peak latency [Z=1.61, p>0.05], for n2 peak latency [Z=0.72, p>0.05], the amplitude complexes of n1-p1 [Z=0.77, p>0.05] and p1-n2 [Z=0.84, p>0.05].

Between the minimal to mild hearing loss and moderate to moderately severe hearing loss group, the Mann-Whitney U test revealed no significant difference for the n1 peak latency [Z=1.19, p>0.05], for p1 peak latency [Z=0.47, p>0.05], for n2 peak latency [Z=0.59, p>0.05], the amplitude complexes of n1-p1 [Z=0.29, p>0.05] and p1-n2 [Z=0.15, p>0.05].

Between the minimal to mild hearing loss and severe to profound hearing loss group, the Mann-Whitney U test revealed significant difference for the p1 peak latency [Z=2.43, p<0.05]and for n2 peak latency [Z=2.43, p<0.05] and there was no significant difference for n1 peak latency [Z=1.17, p>0.05], the amplitude complexes of n1-p1 [Z=0.10, p>0.05] and p1-n2 [Z=0.10, p>0.05].

Between the moderate to moderately severe hearing loss group and severe to profound hearing loss group, the Mann-Whitney U test revealed no significant difference for p1 peak latency [Z=1.27, p>0.05], for n2 peak latency [Z=1.91, p>0.05], the amplitude complexes of n1-p1 [Z=1.55, p>0.05] and p1-n2 [Z=1.27, p>0.05] except for the n1 peak latency [Z=2.26, p<0.05].

To summarize, the p1 latency was significantly more in the minimal to mild hearing loss group compared to the normal hearing group also the n1 latency was significantly more in the moderate to moderately severe hearing loss group and p1-n2 amplitude complex was significantly less in the moderate hearing loss group; also the p1 and n2 latency was significantly more in the minimal to mild hearing loss group compared to severe to profound hearing loss group and the n1 latency was significantly more in the moderate to moderately severe hearing loss group compared to the severe to profound hearing loss group.

**4.2 Subjective visual vertical test findings**

Static SVV was measured for three different static head positions: (a) head centred with 0° tilt, (b) head tilted 30° to the right, and (c) head tilted 30° to the left. The SVV for each participant was calculated as the mean of five trials for each head position.

Descriptive statistics was done to calculate the mean, standard deviation for the for three different static head positions both the groups. The mean values and the standard deviation for three different static head positions for normal hearing group and hearing-impaired group is shown in Table 4.7 and Table 4.8 respectively.

Table 4.7

*Mean and standard deviation at various degrees in Subjective visual vertical test in normal hearing individuals*

| | Mean | SD |
|---|---|---|
| **Zero degree** | 1.03 | 0.58 |
| **Thirty degree right** | 1.49 | 0.71 |

| | | |
|---|---|---|
| **Thirty degree left** | 1.52 | 0.53 |

Table 4.8

*Mean and standard deviation at various degrees in Subjective visual vertical test in hearing impaired group*

| | Head positions | Mean | SD |
|---|---|---|---|
| **Minimal to mild sensorineural hearing loss.** | Zero degree | 1.86 | 0.62 |
| | Thirty degree right | 1.51 | 0.65 |
| | Thirty degree left | 1.38 | 0.47 |
| **Moderate to moderately severe sensorineural hearing loss.** | Zero degree | 2.88 | 1.11 |
| | Thirty degree right | 1.99 | 0.54 |
| | Thirty degree left | 2.58 | 0.94 |
| **Severe to profound sensorineural hearing loss.** | Zero degree | 1.45 | 1.00 |
| | Thirty degree right | 1.37 | 1.12 |
| | Thirty degree left | 1.62 | 0.80 |

It can be seen from Table-4.7 and Table 4.8 that mean tilt of individuals with normal hearing is almost similar to individual with hearing impairment except for the bilateral moderate to moderately severe sensorineural hearing loss group where the tilt is slightly larger.

The obtained data was tested for normality distribution. Shapiro-Wilk test of normality was administered and it was found that the data had normal distribution ($p>0.05$).

To compare significant differences in the mean values of ocular tilt at different head positions between the normal hearing and hearing-impaired individuals the multivariate analysis of variance (MANOVA) was done. Multivariate analysis of variance revealed a significant main effect for zero degree head position [$F(3,52) = 13.56$, $p<0.05$] and thirty degree left head position [$F(3,52) = 6.81$ $p<0.05$]. However, there was no significant main effect for thirty degree right head position [$F(3,52) = 1.23$, $p>0.05$].

In order to determine particularly which of the four groups a significant difference exists, Duncan's post hoc analysis was done. At zero degree head position, the normal hearing and the severe to profound hearing loss group differed significantly from the other two hearing impaired groups ($p<0.05$). The minimal to mild hearing impaired group and the moderate to moderately severe hearing loss group differed significantly from the other hearing impaired groups ($p<0.05$). For the thirty degree right head position, there was no significant difference among all the four groups ($p>0.05$). For the thirty degree left head position, the moderate to moderately severe hearing loss group differed significantly from the other hearing impaired groups and the normal hearing group ($p<0.05$).

Since, there was uneven sample size among the three groups taken for the study, Kruskal-Wallis test was done to cross check the results of the MANOVA. The results of the Kruskal-Wallis also revealed a significant difference at zero degree head position and thirty degree left head position between the groups. Table 4.9 shows Chi- square values along with significant level across the groups.

Table 4.9

*Chi- square values along with significant level across the groups.*

| | **Zero** | **Thirty degree right** | **Thirty degree left** |
|---|---|---|---|
| **Chi square** | 20.79 | 5.03 | 12.33 |

| | | | |
|---|---|---|---|
| **Degrees of freedom (df)** | 3 | 3 | 3 |
| **Significance level** | 0 | 0.169 | 0.006 |

Further to understand the significant difference in the different head positions (zero-degree, thirty degree right and thirty degree left) for the combined data between the normal hearing- and hearing-impaired groups and across the hearing-impaired groups, Mann-Whitney U Test was done. Mann-Whitney U test showed a significant difference for zero-degree head position ($Z$=2.97, $p<0.05$) and no significant difference for thirty-degree right position ($Z$=0.18, $p>0.05$) and thirty-degree left position ($Z$=0.83, $p>0.05$) between the normal hearing and minimal to mild hearing loss group.

Between the normal hearing and moderate to moderately severe hearing loss group, there was no significant difference for thirty-degree right position ($Z$=1.91, $p>0.05$) but zero-degree head position ($Z$=3.89, $p<0.05$) and thirty-degree left position ($Z$=3.40, $p<0.05$) showed a significant difference.

Between the normal hearing and severe to profound hearing loss group, there was no significant difference for zero-degree head position ($Z$=0.79, $p>0.05$), for thirty-degree right position ($Z$=0.97, $p>0.05$) and thirty-degree left position ($Z$=0.61, $p>0.05$).

Between the minimal to mild hearing loss and moderate to moderately severe hearing loss group, there was significant difference for thirty-degree left position ($Z$=2.92, $p<0.05$) and zero-degree head position ($Z$=2.21, $p<0.05$) but thirty-degree right position ($Z$=1.63, $p>0.05$) showed no significant difference.

Between the minimal to mild hearing loss and severe to profound hearing loss group, there was no significant difference for zero-degree head position ($Z$=1.636,

$p>0.05$), for thirty-degree right position ($Z=1.226$, $p>0.05$) and thirty-degree left position ($Z=0.736$, $p>0.05$).

Between moderate to moderately severe hearing loss group and severe to profound hearing loss group, there was significant difference for zero-degree head position ($Z=2.53$, $p<0.05$) but no significant difference for thirty-degree right position ($Z=1.51$, $p>0.05$) and thirty-degree left position ($Z=1.71$, $p>0.05$).

To summarize, the tilt was significantly more at zero degree head position for all the hearing impaired groups compared to the normal hearing group; also the tilt was significantly more at zero degree head position and thirty degree left head position in moderate to moderately severe hearing loss group compared to the normal hearing group & in moderate to moderately severe hearing loss group when compared to the minimal to mild hearing loss group.

### 4.3 Correlation between ocular VEMP and SVV test findings in individuals with various degree of sensorineural hearing loss

Latency and amplitude of the oVEMP were correlated with the various static head position of the subjective visual vertical test (zero-degree, thirty degree right and thirty degree left). Spearman's correlation revealed no correlation between various parameters of oVEMP and different head position of the subjective visual vertical test for the minimal to mild hearing loss group and moderate hearing loss group ($p>0.05$). In the severe to profound hearing loss group there was no correlation between various parameters of oVEMP and different head position of the subjective visual vertical test except for n1-p1 amplitude complex with thirty degree right head tilt ($r=0.76$, $p=0.01$), for p1-n2 amplitude complex with thirty degree right head tilt ($r=0.65$, $p=0.04$) and for n1-p1 amplitude complex with thirty degree left head tilt ($r=0.74$, $p=0.01$) which showed a positive correlation.

### 4.4 Association between degree of hearing loss and oVEMP findings.

To find the association between degree of hearing loss and oVEMP findings chi-square test was done and the values are shown in Table 4.10

Table 4.10

*Association between degree of hearing loss and oVEMP findings*

| | oVEMP | | |
|---|---|---|---|
| | Present | Absent | Total |
| **Mild** | 16 | 2 | 18 |
| **Moderate** | 11 | 7 | 18 |
| **Severe** | 10 | 10 | 20 |
| **Total** | 37 | 19 | 56 |

*p<0.05 (Chi-Square test)

From the above table it was observed that there was association between the degree of hearing loss and the oVEMP responses. As the hearing loss progressed the total present oVEMP responses kept on reducing.

To summarize, oVEMP was present in 100% of the participants in normal hearing group and in the hearing loss group oVEMP was present in 64% of right ears and 67% of left ears.

There was a significant difference in the p1 latency between the normal hearing group and the minimal to mild hearing loss group; in the n1 latency and p1-n2 amplitude complex between the normal hearing group and moderate hearing group and in the p1 and n2 latency between the minimal to mild hearing loss group and severe to profound hearing loss group and n1 latency was significantly more in the moderate to moderately severe hearing loss group compared to the severe to profound hearing loss group.

There was a significant difference at zero degree head position between normal hearing group and minimal to mild hearing loss group & moderate to moderately severe hearing loss group and severe to profound hearing loss group; at zero degree head position and thirty degree left head position between the normal hearing group and moderate to moderately severe hearing loss group & between minimal to mild hearing loss group and moderate to moderately severe hearing loss group.

It was observed that there was association between the degree of hearing loss and the oVEMP responses. As the hearing loss, prevalence of oVEMP reduced in individuals with various degree of sensorineural hearing loss.

# CHAPTER V

# DISCUSSION

The present study was conducted with an aim of assessing the functioning of utricle using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with various degrees of sensorineural hearing loss. The objectives of the study were, assessing the functioning of the utricle in individuals with sensorineural hearing loss using oVEMP and subjective visual vertical test (SVV), studying the correlation between ocular VEMP and SVV test findings in individuals with various degree of sensorineural hearing loss and to find out association between severity of hearing loss with ocular VEMP test findings in individuals with various degree of sensorineural hearing loss. The discussion for the results is given below:

## 5.1 Ocular vestibular evoked myogenic potentials

*oVEMP was present in 100% of the participants in normal hearing group and in the hearing loss group oVEMP was present in 64% of right ears and 67% of left ears. When the data from the right and left ear was combined, the oVEMP was present in 80% of subjects with minimal to mild hearing loss, 55% of subjects with moderate to moderate to moderately severe hearing loss and 50% of individuals with severe to profound hearing loss. Also, there was a significant association between degree of hearing loss and absence of oVEMP responses i.e as the degree of hearing loss increased, the number of oVEMP absent responses also increased.*

The presence of oVEMP in the present study is comparable to the earlier studies. Bansal, Sahni & Sinha (2013) reported presence of oVEMP in 66% of individuals with severe to profound hearing loss. Xu et al. (2015) reported response rates of 61.9% of oVEMP in children with profound sensorineural hearing loss. Niu et al., (2015) reported abnormal oVEMP in 54.8% of individuals with sudden sensorineural hearing loss.

Fujimoto et al. (2015) reported abnormal oVEMP in 43% of subjects with idiopathic sudden sensorineural hearing loss. Xu et al., (2015) reported that response rate of oVEMP in subjects with profound hearing loss was 58.8% and also the amplitude of oVEMP was reduced in subjects with sensorineural hearing loss. Overall the prevalence of oVEMP in this study was similar to the earlier studies, the present study included participants with different degree of hearing loss, and earlier studies have the participants having profound hearing loss only.

*The p1 latency there was a significantly more in the minimal to mild hearing loss group compared to the normal hearing group also the n1 latency was significantly more in the moderate to moderately severe hearing loss group and p1-n2 amplitude complex was significantly less in the moderate hearing loss group; also, the p1 and n2 latency was significantly more in the minimal to mild hearing loss group compared to severe to profound hearing loss group and the n1 latency was significantly more in the moderate to moderately severe hearing loss group compared to the severe to profound hearing loss group. However, there was no consistent pattern of latency prolongation or amplitude reduction of oVEMP in individuals with different degree of hearing loss.*

Bansal (2013) reported no significant difference between the various peak latencies of oVEMP between the normal hearing individuals and individuals with severe to profound hearing loss. But the amplitude complex of n1-p1 and p1-n2 of the individuals with severe to profound hearing loss was significantly smaller compared to the normal hearing individuals. Rashmi (2016) reported prolonged peak latencies of oVEMP in individuals with hearing loss compared to the normal hearing subjects. The author also reported that the n1-p1 and p1-n2 amplitude complex was also significantly smaller in individuals with hearing loss compared to the normal hearing subjects. Xu et al., (2015) reported abnormal oVEMP thresholds, amplitudes, and latencies, and they named this phenomenon as ‘‘VEMP impairment’ in individuals with sensorineural hearing loss. Xu et al. (2016) studied 29 subjects with profound sensorineural hearing loss using oVEMP. They found that that oVEMP had significantly higher threshold and smaller amplitude than cVEMP.

Niu et al., (2015) reported no significant difference in abnormal rates of oVEMP among different degrees of hearing loss. Nagai et al., (2014) performed the BCV-oVEMP test in 65 SSHL patients and found that the rates of abnormal oVEMP tended to be higher in the severe grade. Gao et al., (2015) found that the relationship between vestibular function and different hearing impaired degrees had no statistically significant difference. Lepcha, M., (2018) reported a significant difference between normal hearing and hearing loss group for the amplitude complex of n1-p1 and p1-n2 of oVEMP. Thus, the difference in results between the present study compared to earlier study could be attributed to the type of individuals participated in the studies. Earlier studies have only individuals with profound sensorineural hearing loss whereas, the present study had minimal to profound hearing loss.

Longer latencies are believed to be markers of neural pathologies involving the vestibular nerve, vestibular nuclei or the pathway to the ocular muscles, as in cases of auditory neuropathy spectrum disorders (Singh et al., 2016), vestibular schwanomma (Iwasaki, Murofushi, Chihara & Ushio, 2010) or age related decline (Tseng et al., 2010). The participants in the hearing loss group were devoid of any of the above mentioned pathologies as this was ensured through case history, a battery of audiological tests including auditory brainstem response, oto-acoustic emissions and immittance audiometry. There is a possibility that the idiopathic factor that causes hearing loss, could have caused a decline in the utricular function.

Anatomically and physiologically the two parts of the inner ear i.e the cochlea and the vestibular system are closely related to each other (Tribukait et al., 2004). It has also been reported that there are similarities in the vestibular hair cells and the cochlear hair cells and the blood supply to both the systems (Starr et al., 2003). The cochlea and the vestibular organs share the same membranous labyrinth of the inner ear and hence the abnormality or the dysfunction of one part may lead to dysfunction of the other part too. In the present study, oVEMP in hearing impaired group have reduced response rates compared to the normal hearing individuals. This suggests that there is some form of utricular damage associated with hearing loss. Tribukait et al., (2004) also reported that cochlea is more closely linked to the utricle than the any other sensory receptors of the inner ear. It is possible that vestibular compensation might occur in individuals with hearing loss which explains that even with abnormal oVEMP results they do no report of any vestibular symptoms.

**5.2 Subjective visual vertical test findings**

*Mean ocular tilt of individuals with normal hearing is almost similar to individual with hearing impairment except for the bilateral moderate to moderately severe sensorineural hearing loss group where the ocular tilt is slightly larger. However, the mean ocular tilt for the same group is within the normal limits as reported by the previous studies.*

*At zero degree head position, the normal hearing and the severe to profound hearing loss group differed significantly, but the mean ocular tilt was still within normal limits.*

Bisdorff et al., (1996) studied SVV in 8 subjects with bilateral loss of vestibular function and reported that the ocular tilt in roll plane was not different from normal. Tabak, Collewijn and Boumans (1997) found that the mean SVV ocular tilts in bilateral vestibular dysfunction subjects did not differ significantly from the ocular tilts in the control subjects. Lopez et al., (2007) reported that subjects with bilateral vestibular loss had their SVV aligned with the gravitational vertical. Funabashi et al., (2012) reported that when tested using the conventional method individuals with bilateral vestibular dysfunction did not differ from the healthy volunteers in the perception of SVV. Kim, Na, Park and Shin (2013) reported that abnormal SVV was observed in 10% of individuals with bilateral sudden sensorineural hearing loss with vertigo. Chetna and Jayesh (2015) reported that SVV was insensitive to lateralization in bilateral Meniere's disease.

In the present study, the mean ocular tilt for normal hearing individuals and all the hearing impaired groups was within 3 degrees at all the 3 head positions. Dieterich and Brandt (1993) reported that a ocular tilt of 3 degree or more from vertical is pathological. On the other hand, Ashish, Augustine, Tyagi, Lepcha and Balraj (2016) reported mean value for static SVV to be 1.52° ± 0.70°. However, Jovanovic & Ribaric-Jankes, (2008) reported that the perceived visual vertical in healthy subjects can show deviation with accuracy of ±2° at most. Hafstrom, et al. (2004) reported the normative value to be within ±3.0°

Gavin, Hwang, Cushing and Lin (2016) reported that SVV was deviated in children with severe to profound hearing loss. Ogawa et al (2012) reported that there was >2 degree deviation in the perception of visual vertical found in 26.3% of subjects with sudden sensorineural hearing loss. SVV testing operates on the principle that unilateral utricular hypofunction causes ocular torsion away from the side of the lesion and, consequently, deviation towards the side of the lesion. But in cases with bilateral vestibular pathology the SVV is reported to be within the normal limits.

**5.3 Correlation between SVV and oVEMP findings.**

*Spearman's correlation revealed no correlation between various parameters of oVEMP and different head position of the subjective visual vertical test for the minimal to mild hearing loss group and moderate to moderately severe hearing loss group . In the severe to profound hearing loss group there was no correlation between various parameters of oVEMP and different head position of the subjective visual vertical test except for n1-p1 amplitude complex with thirty degree right head ocular tilt, for p1-n2 amplitude complex with thirty degree right head ocular tilt and for n1-p1 amplitude complex with thirty degree left head ocular tilt which showed a positive correlation.*

Rosengren and Kingma, (2013) reported that the oVEMP correlates better with caloric and subjective visual vertical tests than cVEMPs. Sun et al., (2014) found a significant correlation between SVV measured with the bucket test and the tap-evoked oVEMP asymmetry ratio in older individuals in the aged 70 and above. Nagai et al., (2014) reported that there was no significant difference in the rates of abnormal oVEMP in subjects with sudden sensorineural hearing loss with normal and abnormal SVV. Ogawa et al., (2012) reported that there was no significant relationship between the rates of abnormal SVV and VEMP in subjects with sudden sensorineural hearing loss. There was a significant correlation between mean ocular tilt and oVEMP results in profound hearing loss group only which suggests that the utricular dysfunction could lead to ocular tilt in individuals with profound hearing loss.

# CHAPTER VI

## SUMMARY AND CONCLUSIONS

The inner ear contains two sensory organs namely, auditory and vestibular, connected anatomically and functionally encased within same membranous labyrinth and also shares common labyrinthine artery and same endolymphatic fluid. Therefore, damage or insult to one of the systems can bring about damage to the other system as well. The vestibular system is broadly categorized into both peripheral and central components. The peripheral system is bilaterally composed of three semi-circular canals (posterior, superior, lateral) and the otolithic organs (saccule and utricle). The semi-circular canals detect rotational head movement while the utricle and saccule respond to linear acceleration and gravity, respectively.

Ocular vestibular-evoked myogenic potential (oVEMP) test evaluates the utricular function and the superior vestibular nerve function. Subjective Visual Vertical assesses the ability to perceive verticality which depends on visual, vestibular and somatosensory inputs. The subjective visual vertical is determined by having subjects adjust a visible luminous line in complete darkness to what they consider to be upright, earth vertical. The subjective visual vertical (SVV) is a perception often impaired in patients with neurologic disorders and is considered as a sensitive tool to detect otolithic dysfunctions.

Hence, the present study was conducted with an aim of assessing the functioning of utricle using ocular vestibular evoked myogenic potentials and subjective visual vertical test in individuals with various degrees of sensorineural hearing loss. The objectives of the study were:

- To assess the functioning of the utricle in individuals with sensorineural hearing loss using oVEMP and Subjective visual vertical test (SVV).

- ❖ To find out the correlation between ocular VEMP and SVV test findings in individuals with various degree of sensorineural hearing loss.
- ❖ To find out the association between severity of hearing loss with ocular VEMP test findings in individuals with various degree of sensorineural hearing loss.

To meet the aim of the study, the participants were divided in to two groups. Group I consisted of 28 participants (12 males and 18 females) with various degree of sensorineural hearing loss within the age range of 18-40 years. Out of 28 participants, 9 participants had minimal to mild sensorineural hearing loss, 9 participants had moderate to moderately severe sensorineural hearing loss and 10 participants had severe to profound sensorineural hearing loss. Group II consisted of 28 participants with normal hearing (12 males & 18 females) within the age range of 18-40 years. All the participants in both the groups underwent a detailed case history, pure tone audiometry, immittance audiometry and acoustic reflex threshold test, oVEMP and SVV.

oVEMP was recorded using 500Hz tone burst stimuli presented at 125 dBSPL. The positive electrode was placed 1cm below the eyes, negative electrode was placed 1cm below the positive electrode and ground electrode was placed on the forehead. The responses were analyzed in a 60msec time window including 10msec pre-stimulus time. SVV was recorded at three static head positions: zero degree and thirty degree right and left.

For oVEMP, the n1, p1, n2 peak latency and n1-p1 and p1-n2 amplitude complex analysis was carried out. For SVV the verticality perceived by the individuals at 0 degree, 30 degree to right and 30 degree to left were taken. An average of six trials was taken as the absolute value.

- ❖ Descriptive statistics was done to calculate the mean and standard deviation for oVEMP and SVV for both the groups.

- Shapiro Wilk test was done to check the normal distribution of the cVEMP and oVEMP data.
- Paired Sample T test was done to compare the oVEMP parameters between right and the left ear.
- Multivariate analysis of variance was done to check the significant difference in the mean values of oVEMP parameters between the normal hearing and hearing impaired group.
- Kruskal Wallis Test was done to check the significant difference in oVEMP parameters between the normal hearing and hearing impaired group, since the different groups contained different data samples.
- Mann-Whitney U test was done to check the significant difference in mean latencies and amplitude of oVEMP parameters between the normal hearing and hearing impaired group and also between the three hearing impaired groups.
- Chi-square test was done to find out the association between degree of hearing loss and oVEMP parameters.
- Spearman Correlation was done to check any correlation between oVEMP and SVV test findings.
- Multiple analysis of variance was done to check the significant difference in the mean values of SVV parameters between the normal hearing and hearing impaired group.
- Kruskal Wallis Test was done to check the significant difference in SVV parameters between the normal hearing and hearing impaired group, since the different groups contained different data samples.

- ❖ Mann-Whitney U test was done to check the significant difference in mean ocular tilt between the normal hearing and hearing impaired group and also between the three hearing impaired groups.

The result obtained for the above statistical analysis revealed the following:

**1. Ocular vestibular evoked myogenic potentials**

- ❖ oVEMP was present in 100% of the participants and in the hearing loss group oVEMP was present in 64% (18 out of 28) of right ears and 67% (19 out of 28) of left ears.
- ❖ The p1 latency was significantly more in the minimal to mild hearing loss group compared to the normal hearing group also the n1 latency was significantly more in the moderate to moderately severe hearing loss group and p1-n2 amplitude complex was significantly less in the moderate hearing loss group; also the p1 and n2 latency was significantly more in the minimal to mild hearing loss group compared to severe to profound hearing loss group the n1 latency was significantly more in the moderate to moderately severe hearing loss group compared to the severe to profound hearing loss group.
- ❖ There was an association between the degree of hearing loss and the oVEMP responses. As the hearing loss progressed the total present oVEMP responses kept on reducing.

**2. Subjective visual vertical test**

- ❖ The mean ocular tilt of individuals with normal hearing is almost similar to individual with hearing impairment except for the bilateral moderate to moderately severe sensorineural hearing loss group where the ocular tilt was slightly larger.

- ❖ The perception in ocular tilt was significantly more at zero degree head position for all the hearing impaired groups compared to the normal hearing group; also the tilt was significantly more at zero degree head position and thirty degree left head position in moderate to moderately severe hearing loss group compared to the normal hearing group & in moderate to moderately severe hearing loss group when compared to the minimal to mild hearing loss group. However, the ocular tilt of both the groups are within the normal range as per the normative data of SVV cited in different articles.

# CONCLUSIONS

oVEMP and SVV together provide us information about the utricular function. Thus, these tests can be used to identify and diagnose various utricular pathologies. Findings of the present study suggest that there is utricular dysfunction in individuals with hearing loss as compared to the normal hearing individuals. oVEMP revealed the utricular dysfunction however, the SVV was within normal limits for both the groups. There was no association seen between the oVEMP and SVV test findings in the hearing impaired population. To conclude, individuals with hearing loss may have utricular dysfunction and individuals with higher degree of hearing loss may have more utricular dysfunction. The SVV may not be an ideal test in finding out the ocular tilt in individuals with bilateral symmetrical sensorineural hearing loss. However, the utricular evaluation must be carried out in individuals with different degrees of hearing impairment.

## Implications of the study

This study provides information regarding the diagnostic significance of utricular evaluation in individuals with sensorineural hearing loss. The results of the present findings will help the clinicians in making a vestibular rehabilitation programme for individuals with different degree of hearing loss with utricular dysfunction.

## REFERENCES


American National Standards Institute. (1999). *Maximum permissible ambient noise levels for audiometric test rooms* (ANSI S3.1-1999). New York.

Ashish, G., Augustine, A. M., Tyagi, A. K., Lepcha, A., & Balraj, A. (2016). Subjective visual vertical and horizontal: Normative values using a software-based test in the Indian population. *Indian Journal of Otology*, *22*(3), 208.

Bansal, S., Sahni, S., & Sinha, S. (2013). Cervical and ocular vestibular evoked myogenic potentials in individuals with severe to profound hearing loss. *Journal of Hearing Science*, *3*(4), 56-63.

Bisdorff, A. R., Wolsley, C. J., Anastasopoulos, D., Bronstein, A. M., &Gresty, M. A. (1996). The perception of body verticality (subjective postural vertical) in peripheral and central vestibular disorders. *Brain*, *119*(5), 1523-1534.

Böhmer, A., &Rickenmann, J. (1995). The subjective visual vertical as a clinical parameter of vestibular function in peripheral vestibular diseases. *Journal of Vestibular Research*, *5*(1), 35-45.

Bremova, T., Bayer, O., Agrawal, Y., Kremmyda, O., Brandt, T., Teufel, J., &Strupp, M. (2013). Ocular VEMPs indicate repositioning of otoconia to the utricle after successful liberatorymaneuvers in benign paroxysmal positioning vertigo. *Acta Oto-Laryngologica*, *133*(12), 1297-1303.

Carhart, R., & Jerger, J.F.(1959). Preferred Method For Clinical Determination Of Pure-Tone Thresholds.*Journal of Speech and Hearing Disorders*, *24*, 330-345.

Chen, C. W., Young, Y. H., & Wu, C. H. (2000). Vestibular neuritis: three-dimensional videonystagmography and vestibular evoked myogenic potential results. *Acta Oto-Laryngologica*, *120*(7), 845-848

Chetana, N., & Jayesh, R. (2015). Subjective visual vertical in various vestibular disorders by using a simple bucket test. *Indian Journal of Otolaryngology and Head & Neck Surgery*, *67*(2), 180-184.

Chiarovano, E., Zamith, F., Vidal, P. P., & de Waele, C. (2011). Ocular and cervical VEMPs:a study of 74 patients suffering from peripheral vestibular disorders. *Clinical Neurophysiology*, *122*(8), 1650-1659.

Cohen, H. S., & Sangi-Haghpeykar, H. (2012). Subjective visual vertical in vestibular disorders measured with the bucket test. *Acta Oto-laryngologica*, *132*(8), 850-854.

Curthoys, I. S., Iwasaki, S., Chihara, Y., Ushio, M., McGarvie, L. A., & Burgess, A. M. (2011). The ocular vestibular-evoked myogenic potential to air-conducted sound; probable superior vestibular nerve origin. *Clinical Neurophysiology*, *122*(3), 611-616.

Cushing, S. L., Gordon, K. A., Rutka, J. A., James, A. L., &Papsin, B. C. (2013). Vestibular end-organ dysfunction in children with sensorineural hearing loss and cochlear implants: an expanded cohort and etiologic assessment. *Otology & Neurotology*, *34*(3), 422-428.

Davies, R. A., &Luxon, L. M. (1995). Dizziness following head injury: a neuro-otological study. *Journal of Neurology*, *242*(4), 222-230.

Deafness and hearing loss. Retrieved from http://www.who.int/news-room/fact-sheets/detail/deafness-and-hearing-loss.

Dieterich, M., & Brandt, T. (1993). Ocular torsion and tilt of subjective visual vertical are sensitive brainstem signs. *Annals of Neurology*, *33*(3), 292-299.

Egami, N., Ushio, M., Yamasoba, T., Yamaguchi, T., Murofushi, T., & Iwasaki, S. (2013). The diagnostic value of vestibular evoked myogenic potentials in patients with Meniere's disease. *Journal of Vestibular Research*, *23*(4, 5), 249-257.

Epley, J. M. (1992). The canalith repositioning procedure: for treatment of benign paroxysmal positional vertigo. *Otolaryngology—Head and Neck Surgery*, *107*(3), 399-404.

Friedmann, G. (1970). The judgement of the visual vertical and horizontal with peripheral and central vestibular lesions. *Brain*, *93*(2), 313-328.

Fujimoto, C., Egami, N., Kinoshita, M., Sugasawa, K., Yamasoba, T., & Iwasaki, S. (2015). Involvement of vestibular organs in idiopathic sudden hearing loss with vertigo: an analysis using oVEMP and cVEMP testing. *Clinical Neurophysiology*, *126*(5), 1033-1038.

Funabashi, M., Santos-Pontelli, T. E. G., Colafeˆmina, J. F., Pavan, T. Z., Carneiro, A. A. O., & Takayanagui, O. M. (2012). A new method to analyze the subjective visual vertical in patients with bilateral vestibular dysfunction. *Clinics*, *67*(10), 1127-1131.

Gall, R. M., Ireland, D. J., & Robertson, D. D. (1999). Subjective visual vertical in patients with benign praxysmal positional vertigo. *Journal of Otolaryngology-Head & Neck Surgery*, *28*(3), 162-165.

Gao, Y., Wang, D., Su, Q., Wang, H., Lan, L., Yin, Z.,.& Wang, Q. (2015). Study of clinical characteristics and curative effects of sudden hearing loss patients with vertigo. *Chinese Journal of Otorhinolaryngology Head and Neck Surgery*, *50*(7), 529-535.

Gavin, J., Hwang, E., Wu, A., Cushing, S., & Lin, V. Y. (2016). Vestibular function following unilateral cochlear implantation for profound sensorineural hearing loss. *Journal of Otolaryngology-Head & Neck Surgery*, *45*(1), 38.

Gnanasegaram, J. J., Parkes, W. J., Cushing, S. L., McKnight, C. L., Papsin, B. C., & Gordon, K. A. (2016). Stimulation from cochlear implant electrodes assists with recovery from asymmetric perceptual tilt: evidence from the subjective visual vertical test. *Frontiers in Integrative Neuroscience*, *10*, 32.

Hafström, A., Fransson, P. A., Karlberg, M., & Magnusson, M. (2004). Idiosyncratic compensation of the subjective visual horizontal and vertical in 60 patients after unilateral vestibular deafferentation. *Acta Oto-laryngologica*, *124*(2), 165-171.

Hornibrook, J. (2011). Benign paroxysmal positional vertigo (BPPV): history, pathophysiology, office treatment and future directions. *International Journal of Otolaryngology*, *2011*.

Iwasaki, S., Murofushi, T., Chihara, Y., Ushio, M., Suzuki, M., Curthoys, I. S., & Yamasoba, T. (2010). Ocular vestibular evoked myogenic potentials to bone-conducted vibration in vestibular schwannomas. *Otology & Neurotology*, *31*(1), 147-152.

Jing, L. I., Liu, X., Liu, C., Liu, S., Zhang, S., &Ziming, W. U. (2017). Study on difference of vestibular damage of sudden deafness and vestibular neuritis. *Chinese Archives of Otolaryngology-Head and Neck Surgery*, *24*(1), 25-27.

Jovanović, S., & Ribarić-Jankes, K. (2008). Subjective Visual Vertical test: normative values in healthy population. *Srpski arhiv za celokupno lekarstvo*, *136*(11-12), 585-589.

Kalaiah, M. K., Kumar, A., & Ranjan, R. (2014). Vestibular evoked myogenic potential response in acquired sensory neural hearing loss. *International Journal of Innovative Research Development*, *3*, 31-7.

Kim, C. H., Na, B. R., Park, H. J., & Shin, J. E. (2013). Impairment of static vestibular function is limited in patients with sudden sensorineural hearing loss with vertigo. *Audiology and Neurotology*, *18*(4), 208-213.

Kumagami, H., Sainoo, Y., Fujiyama, D., Baba, A., Oku, R., Takasaki, K.,& Takahashi, H. (2009). Subjective visual vertical in acute attacks of Ménière's disease. *Otology &Neurotology*, *30*(2), 206-209.

Lee, J. D., Park, M. K., Lee, B. D., Lee, T. K., Sung, K. B., & Park, J. Y. (2013). Abnormality of cervical vestibular-evoked myogenic potentials and ocular vestibular-evoked myogenic potentials in patients with recurrent benign paroxysmal postitional vertigo. *Acta Oto-laryngologica*, *133*(2), 150-153.

Lepcha, M., (2018). Assessment of otolithic and semi-circular canal function in individuals with sensorineural hearing loss. Unpublished dissertation submitted to University of Mysore, Mysore.

Lin, K. Y., & Young, Y. H. (2011). Correlation between subjective visual horizontal test and ocular vestibular-evoked myogenic potential test. *Acta Oto-laryngologica*, *131*(2), 149-155.

Lopez, C., Lacour, M., El Ahmadi, A., Magnan, J., &Borel, L. (2007). Changes of visual vertical perception: a long-term sign of unilateral and bilateral vestibular loss. *Neuropsychologia*, *45*(9), 2025-2037.

Manzari, L., Tedesco, A. R., Burgess, A. M., &Curthoys, I. S. (2010). Ocular and cervical vestibular-evoked myogenic potentials to bone conducted vibration in Ménière's disease during quiescence vs during acute attacks. *Clinical Neurophysiology*, *121*(7), 1092-1101.

McClure, J. A. (1985). Horizontal canal BPV. *The Journal of otolaryngology*, *14*(1), 30-35.

Min, K. K., Ha, J. S., Kim, M. J., Cho, C. H., Cha, H. E., & Lee, J. H. (2007). Clinical use of subjective visual horizontal and vertical in patients of unilateral vestibular neuritis. *Otology & Neurotology*, *28*(4), 520-525.

Moon, I. H., Lee, C. G., Park, M. K., & Lee, J. D. (2012). Cervical vestibular evoked myogenic potential and ocular vestibular evoked myogenic potential in patients with vestibular neuritis and acute viral labyrinthitis. *Research in Vestibular Science*, *11*(3), 92-96.

Murofushi, T., Nakahara, H., Yoshimura, E., & Tsuda, Y. (2011). Association of air-conducted sound oVEMP findings with cVEMP and caloric test findings in patients with unilateral peripheral vestibular disorders. *Acta Oto-laryngologica*, *131*(9), 945-950.

Nagai, N., Ogawa, Y., Hagiwara, A., Otsuka, K., Inagaki, T., Shimizu, S., & Suzuki, M. (2014). Ocular vestibular evoked myogenic potentials induced by bone-conducted vibration in patients with unilateral inner ear disease. *Acta Oto-laryngologica*, *134*(2), 151-158.

Nakahara, H., Yoshimura, E., Tsuda, Y., &Murofushi, T. (2013). Damaged utricular function clarified by oVEMP in patients with benign paroxysmal positional vertigo. *Acta Oto-laryngologica*, *133*(2), 144-149.

Niesten, M. E., McKenna, M. J., Herrmann, B. S., Grolman, W., & Lee, D. J. (2013). Utility of cVEMPs in bilateral superior canal dehiscence syndrome. *The Laryngoscope*, *123*(1), 226-232.

Niu, X. R., Zhang, Q., Han, P., Wu, C. Q., Du, X. Y., Li, J. J., & Xu, M. (2015). Vestibular dysfunction in patients with sudden sensorineural hearing loss without vertigo. *Journal of Sichuan University. Medical Science Edition*, *46*(3), 426-430.

Noh, H., &Chae, S. (2007). Change of Subjective Visual Vertical (SVV) in Patients of Vestibular Neuritis. *Journal of the Korean Balance Society*, *6*(2), 143-149.

Ogawa, Y., Otsuka, K., Shimizu, S., Inagaki, T., Kondo, T., & Suzuki, M. (2012). Subjective visual vertical perception in patients with vestibular neuritis and sudden sensorineural hearing loss. *Journal of Vestibular Research*, *22*(4), 205-211.

O'reilly, R. C., Morlet, T., Nicholas, B. D., Josephson, G., Horlbeck, D., Lundy, L., & Mercado, A. (2010). Prevalence of vestibular and balance disorders in children. *Otology & Neurotology*, *31*(9), 1441-1444.

Pagarkar, W., Bamiou, D. E., Ridout, D., &Luxon, L. M. (2008). Subjective visual vertical and horizontal: effect of the preset angle. *Archives of Otolaryngology–Head & Neck Surgery*, *134*(4), 394-401.

Rashmi, E. (2016). Effect of degree of acquired cochlear hearing loss on ocular vestibular evoked myogenic potential. Unpublished dissertation submitted to University of Mysore, Mysore.

Rauch, S. D., Zhou, G., Kujawa, S. G., Guinan, J. J., & Herrmann, B. S. (2004). Vestibular evoked myogenic potentials show altered tuning in patients with Meniere’s disease. *Otology & Neurotology*, *25*(3), 333-338.

Rosengren, S. M., &Kingma, H. (2013). New perspectives on vestibular evoked myogenic potentials. *Current Opinion in Neurology*, *26*(1), 74-80.

Rosengren, S. M., Aw, S. T., Halmagyi, G. M., Todd, N. M., & Colebatch, J. G. (2008). Ocular vestibular evoked myogenic potentials in superior canal dehiscence. *Journal of Neurology, Neurosurgery & Psychiatry*, *79*(5), 559-568.

Shin, B. S., Oh, S. Y., Kim, J. S., Kim, T. W., Seo, M. W., Lee, H., & Park, Y. A. (2012). Cervical and ocular vestibular-evoked myogenic potentials in acute vestibular neuritis. *Clinical Neurophysiology*, *123*(2), 369-375.

Singh, N. K., & Barman, A. (2016). Frequency–Amplitude Ratio of Ocular Vestibular-Evoked Myogenic Potentials for Detecting Meniere's Disease: A Preliminary Investigation. *Ear and hearing*, *37*(3), 365-373.

Singh, N. K., & Barman, A. (2016). Utility of the frequency tuning measure of oVEMP in differentiating Meniere's disease from BPPV. *Journal of the American Academy of Audiology*, *27*(9), 764-777.

Singh, N. K., &Apeksha, K. (2016). Efficacy of cervical and ocular vestibular-evoked myogenic potentials in evaluation of benign paroxysmal positional vertigo of posterior semicircular canal. *European Archives of Oto-Rhino-Laryngology*, *273*(9), 2523-2532.

Singh, N. K., Sinha, S. K., & Barman, A. (2016). Assessment of otolith mediated neural reflexes through cervical and ocular vestibular evoked myogenic potentials in individuals with auditory neuropathy spectrum disorders. *Hearing, Balance and Communication*, *14*(2), 77-90.

Sinha, S. K., Shankar, K., &Govindaswamy, R. (2015). cVEMP, oVEMP and Caloric Test Results in Individuals with Meniere's Disease. *International Journal of Speech & Language Pathology and Audiology*, *3*(2), 93-102.

Sinha, S. K., Shankar, K., &Sharanya, R. (2013). Cervical and ocular vestibular evoked myogenic potentials test results in individuals with auditory neuropathy spectrum disorders. *Audiology research*, *3*(1).

Starr, A., Michalewski, H. J., Zeng, F. G., Fujikawa-Brooks, S., Linthicum, F., Kim, C. S., ... & Keats, B. (2003). Pathology and physiology of auditory neuropathy with a novel mutation in the MPZ gene (Tyr145→ Ser). *Brain*, *126*(7), 1604-1619.

Sun, D. Q., Zuniga, M. G., Davalos-Bichara, M., Carey, J. P., & Agrawal, Y. (2014). Evaluation of a bedside test of utricular function–the bucket test–in older individuals. *Acta Oto-laryngologica*, *134*(4), 382-389.

Tabak, S., Collewijn, H., &Boumans, L. J. J. M. (1997). Deviation of the subjective vertical in long-standing unilateral vestibular loss. *Acta Oto-laryngologica*,*117*(1), 1-6.

Tarnutzer, A. A., Fernando, D. P., Kheradmand, A., Lasker, A. G., & Zee, D. S. (2012). Temporal constancy of perceived direction of gravity assessed by visual line adjustments. *Journal of Vestibular Research*, *22*(1), 41-54.

Tribukait, A., Brantberg, K., &Bergenius, J. (2004). Function of semicircular canals, utricles and saccules in deaf children. *Acta Oto-laryngologica*,*124*(1), 41-48.

Tseng, C. L., Chou, C. H., & Young, Y. H. (2010). Aging effect on the ocular vestibular-evoked myogenic potentials. *Otology & Neurotology*, *31*(6), 959-963.

Vibert, D., & Safran, A. B. (1999). Subjective visual vertical in peripheral unilateral vestibular diseases. *Journal of Vestibular Research*, *9*(2), 145-152.

Vibert, D., Häusler, R., Safran, A. B., & Koerner, F. (1995). Ocular tilt reaction associated with a sudden idiopathic unilateral peripheral cochleovestibular loss. *Journal for Oto-Rhino-Larngology and its Related Speacialities*, *57*(6), 310-315.

Welgampola, M. S., & Colebatch, J. G. (2005). Characteristics and clinical applications of vestibular-evoked myogenic potentials. *Neurology*, *64*(10), 1682-1688.

Wolter, N. E., Cushing, S. L., Madrigal, L. D. V., James, A. L., Campos, J., Papsin, B. C., & Gordon, K. A. (2016). Unilateral hearing loss is associated with impaired balance in children: a pilot study. *Otology & Neurotology*, *37*(10), 1589-1595.

Xu, H., Liang, F. Y., Chen, L., Song, X. C., Tong, M. C. F., Thong, J. F., ... & Sun, Y. (2016). Evaluation of the utricular and saccular function using oVEMPs and cVEMPs in BPPV patients. *Journal of Otolaryngology-Head & Neck Surgery*, *45*(1), 12.

Xu, X. D., Ding, C. R., Yu, J., Han, Z., Gu, J., Gao, N., & Chi, F. L. (2016). The hidden dysfunction of otolithic organs in patients with profound sensorineural hearing loss. *Hearing Research*, *331*, 41-46.

Xu, X. D., Zhang, Q., Hu, J., Zhang, Y., Chen, Y. F., Zhang, X. T., & Xu, M. (2015). The hidden loss of otolithic function in children with profound sensorineural hearing loss. *International Journal of Pediatric Otorhinolaryngology*, *79*(6), 852-857.

Zhang, Q., Hu, J., Xu, X. D., Chen, Y. F., Zhang, Y., Wei, J. R., &Kimitaka, K. (2013). Objective evaluation of otolithic end organs in sudden sensorineural hearing loss patients. *Chinese Journal of Otorhinolaryngology Head and Neck Surgery*, *48*(5), 389-393.

Zhou, G., Kenna, M. A., Stevens, K., & Licameli, G. (2009). Assessment of saccular function in children with sensorineural hearing loss. *Archives of Otolaryngology–Head & Neck Surgery*, *135*(1), 40-44.

Zhou, Y., Wu, Y., & Wang, J. (2016). Otolithic organ function in patients with profound sensorineural hearing loss. *Journal of Otology*, *11*(2), 73-77.

Zuniga, M. G., Janky, K. L., Nguyen, K. D., Welgampola, M. S., & Carey, J. P. (2013). Ocular vs. cervical VEMPs in the diagnosis of superior semicircular canal dehiscence syndrome. *Otology &Neurotology*, *34*(1), 121-126.

Zwergal, A., Rettinger, N., Frenzel, C., Dieterich, M., Brandt, T., &Strupp, M. (2009). A bucket of static vestibular function. *Neurology*, *72*(19), 1689-1692.