VESTIBULO-OCULAR REFLEX GAIN MEASUREMENT USING HEAD IMPULSE PARADIGM AND SUPPRESSION HEAD IMPULSE PARADIGM IN OLDER ADULTS

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CERTIFICATE

This is to certify that this dissertation entitled **'Vestibulo-Ocular Reflex gain measurement using Head Impulse Paradigm and Suppression Head Impulse Paradigm in older adults'** is the bonafide work submitted in part fulfilment for the Degree of Master of Science (Audiology) of the student with Registration No: **18AUD004**. 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.

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CERTIFICATE

This is to certify that this dissertation entitled **'Vestibulo-Ocular Reflex gain measurement using Head Impulse Paradigm and Suppression Head Impulse Paradigm in older adults'** 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.

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DECLARATION

This is to certify that this Master's dissertation entitled **'Vestibulo-Ocular Reflex gain measurement using Head Impulse Paradigm and Suppression Head Impulse Paradigm in older adults'** is the result of my own study under the guidance of Dr. Sujeet Kumar Sinha, Associate Professor 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, **Anagha.A.P**

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Dedicated to my

Achan and Amma

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"A moment of gratitude makes a difference in your attitude."

It is said that there's no happier person than a truly thankful content person…And so am I…coz am blessed with handful of wonderful people…

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ABSTRACT

Aim: The aim of the study was to study the VOR gain values using Head Impulse Paradigm and Suppression Head Impulse Paradigm in older adults.

Methods: Two groups of participants were taken for the study. Group I consisted of 30 participants (15 males and 15 females) within the age range of 41-70 years (older adults). Group II included 30 participants (15males and 15 females) within the age ranging from 18-40 years (younger adults). Participants of both groups had bilateral sensorineural hearing loss. All the participants in both the groups underwent a detailed case history, pure tone audiometry, immittance audiometry, acoustic reflex threshold test, ABR- site of lesion test, Head impulse paradigm and Suppression head impulse paradigm.

Results: All the participants of the study had normal HIMP VOR gain. SHIMP VOR gain was within normative for all the participants of younger adult group. Whereas few participants of the older adult group had reduced or poorer SHIMP VOR gain and few had absent anticompensatory saccade. The VOR gain obtained using HIMP and SHIMP was higher for younger adults compared to that of older adults. No association between the degree of hearing loss and VOR gain for both HIMP and SHIMP for both ears was found. Also, the comparison of VOR gain values of both HIMP and SHIMP between male and female participants revealed no significant difference between groups.

Conclusion: HIMP and SHIMP protocols are valuable tools to evaluate VOR during high-velocity head movements. Both the test protocols can be complementary methods for a comprehensive evaluation of vestibular function in individuals diagnosed with sensorineural hearing loss. VOR gain obtained using HIMP and SHIMP reduces as age increases and it is independent of hearing loss and was not affected by the gender.

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Chapter-I

Introduction

The two similar but different organs are situated in the inner ears, which are responsible for hearing and balance. The same receptors and internal fluid make them comparable and their functions make them different (Ji & Zhai, 2018). The cochlea is stimulated with an auditory stimulus. Thus, it helps in the detection of sound and whereas vestibular organs help in detecting movement of the head and stabilize the image during the head movements. The vestibular system can be considered to be both sensory as well as motor system (Horak & Shupert, 1994). The former one as it helps in an accurate representation of self-motion and the latter one as it coordinates postural and ocular motor reflexes to ensure dynamic and static equilibrium. As age increases, the central nervous system will face complications in dealing with decreased sensorial information as degeneration increases and greater fall in the number of vestibular receptor ganglion cells and labyrinthine hair cells (Zalewski, 2015).

The most common among the vestibular disorders exhibited in the elderly population is dizziness. Agrawal et al., (2009) reported that in individuals aged 40-49; vestibular symptoms are evident in 18% of adults, 49% individuals between 60 to 69 years of age and greater than 80% of people who are over 80 years of age. Tinetti et al., (2000) reported vestibular symptoms in 24% of the individuals aged over 72 years, whereas Sloane et al., (2001) reported vestibular symptoms in more than 30% of the elderly individuals. A review was done with 1194 patients, who are over 70 years.

The central nervous system and other sensory systems are affected by variety of illness and dizziness is very often considered as an obscure symptom associated with them. This fact can be considered to the uncertainty in diagnosis (Shoair et al., 2011). The plethora of studies have documented that the prevalence of vestibular dysfunction progresses with age. According to Dewane (1995), dizziness and fall are the most frequent problems experienced by the elderly. Vestibular dysfunction considerably leads to falls in the elderly (Liston et al., 2014). Falls and related injuries are one of the major causes of death (Dunn et al., 1992).

The dysfunction of the vestibular system in elderly individuals or the presbystasis is responsible for falls in elderly individuals. The vestibular organs include the utricle, saccule, and three semi-circular canals. It is the utricle and saccule which are accountable for identifying linear accelerations of head. The function of horizontal, anterior, and posterior semi-circular canals is mainly to identify head rotations around a vertical, sagittal, and frontal plane, respectively (Ji & Zhai, 2018). One of the major vestibular dysfunction occurs with the vestibulo-ocular reflex (VOR) pathway in older individuals. Individuals with weakened VOR have difficulty stabilizing image in his/her visual field and hence affect reading, walking etc. The video head impulse test which is also known as Halmagyi-Curthoys test in which brief, rapid movement is imposed on the head either in left or right direction and inspecting whether individual can succeed in sustaining eyes on the given target can be used to test VOR reflex clinically. This test provides information regarding the vestibuloocular reflex and thus about the vestibular system and its function (McGarvie et al., 2014).

1.1 Need of the study

1.1.1 Need for vestibular evaluation in older adults

There is a very high rate of incidence and prevalence of various types of balance disorders, including dizziness affecting both genders in old age. There are numerous factors upon which the balance is depended and it includes adequate functioning of all structures that includes sensory, vestibular and even somatosensory structures, also cognition. The common illnesses of aging like cardiovascular, metabolic and disorders of central nervous system can be the reason for compromised sensory structures and also senility of both peripheral and central vestibular system can be one of them (Swain et al., 2018).

Dizziness is one of the vestibular disorders that significantly weaken the quality of life of older individuals. Both severe physical and emotional difficulties, along with the failure to perform daily activities, are the resultant functional limitations of these symptoms.

Studies show that the incidence of falls increases with age (Gama & Gómez-Conesa, 2008; Hsiao et al., 2012; Salvà et al, 2004). The difference between young and older individuals is even more apparent in those tasks demanding more of the postural control system (Mourey et al., 1998). Processing of inputs from vestibular, visual, and somatosensory systems together maintains gaze stability and postural stability while walking and standing still. Each factor in these systems deteriorates with aging (Iwasaki &Yamasoba, 2015). Considering the diversity of vestibular symptoms associated with aging, there is a need to carry out the vestibular evaluation in elderly individuals.

1.1.2 Need for studying VOR gain in older adults

A high-frequency horizontal HIT was carried out by Mossman et al., (2015) and reported that VOR gain decreases a little with age. The anatomical deterioration that happens due to the increase in age reported in peripheral vestibular structure is consistent with the age-related deviations in VOR response obtained by means of a search coil technique (Paige, 1989). The normal VOR performance is preserved by adaptive plastic mechanisms, but this also decline with age (Paige, 1991). Using a search coil technique, the vestibulo-ocular reflex (VOR) in people older than 75 years was reported to be reduced due to age related degeneration of vestibular system (Baloh et al., 1993; Paige, 1992). In another study comprising of 57 elderly people having no symptoms of balance disorders and amplitude-dependent reduction in VOR gain and a growth in phase lead of low-frequency sinusoidal responses were attained over five yearly checkups (Baloh et al, 2001).

An increase in latency and reduction in the amount of catch-up saccades were obtained in individuals over 55 years of age when compared with young adults aged 18 to 31 years using magnetic search coils (Tian et al., 2002). Utilizing video head impulse test it was stated a significant decrease in VOR gain in individuals within the age ranging from 61-70 years (Jha, 2016). However, there is a dearth of studies analyzing the VOR gain using the head impulse paradigm (HIMP) and suppression head impulse paradigm (SHIMP) in elderly individuals. Thus, there is a need to carry out more studies in aged individuals with sensorineural hearing loss to understand the change in VOR gain.

1.1.3 Need for studying Head Impulse Paradigm vs Suppression Head Impulse Paradigm

Rey-Martinez et al. (2018) compared the VOR gain using the HIMP and SHIMP paradigm and they found a difference in VOR gain values in participants with normal vestibular system and participants with vestibular pathology. The authors suggested that supporting strategy for suppression paradigm is the VOR inhibition, and it can also be considered as the underlying mechanism for the SHIMP and HIMP VOR gain differences observed. Shen et al., (2016) carried out SHIMP paradigm in normal and patients with various vestibular pathologies with unilateral or bilateral vestibular loss. The results indicated that patients with bilateral vestibular loss had no anti- compensatory saccades on both sides. In patients with unilateral vestibular loss, zero or very few anti-compensatory saccades were found at the lesion side, and they were of low velocity, compared to that at the intact side. SHIMP paradigm focuses on VOR gain and magnitude of the anti compensatory saccade. Rather than vestibular function, there are various other factors which alter the amplitude of corrective saccade, such as head velocity and degree of overshoot (Curthoys & Manzari, 2017). The SHIMP gain value was lower than HIMP gain value (Devantier et al., 2018). There is a need to investigate this hypothesis as number of studies comparing VOR gain utilizing the HIMP vs SHIMP paradigm are less in the literature.s

1.2 Aim of the study

The present study aimed to study VOR gain values using Head Impulse Paradigm and Suppression Head Impulse Paradigm in older adults.

1.3 Objectives of the study

1) To study the VOR gain values using Head Impulse Paradigm VS Suppression Head Impulse Paradigm in older adults
2) To study an association between the degree of hearing loss and VOR gain in younger and older adults.
3) To compare the VOR gain values between an older male and female participants.

Chapter-II

Review of literature

Sensorineural hearing loss (SNHL) is the most common type of sensory impairment and more than 360 million people are affected by this worldwide, and hence irrespective of etiology, it is considered as a public health problem (Nakagawa, 2014). A significant number of patients with SNHL also have dizziness and related vestibular symptoms (Kerber & Baloh, 2011). Therefore, an association between SNHL and vestibular dysfunction is highly possible in the absence of evidence of any inner ear or systemic vestibulopathy diseases. In addition, vestibular dysfunction was identified in about 20%-70% of children with hearing loss due to various causes (Arnvig, 1955).

2.1 Vestibular dysfunction in sensorineural hearing loss

Vestibular-evoked myogenic potentials were found to be abnormal in children diagnosed to have sensorineural hearing loss. Singh et al., (2012) studied fifteen with severe to profound sensorineural hearing loss and ten children with hearing sensitivity within normal limits. Vestibular-evoked myogenic potentials (VEMP) testing was done for all children to assess saccular function. The authors reported a normal latency of VEMP but reported reduced amplitude of VEMP in these children with sensori neural hearing loss. The authors concluded that there could be a presence of vestibular dysfunction in children with sensorineural hearing loss and also indicated the benefit of vestibular evaluation in such population.

Bansal and Sahni (2013) recorded Vestibular evoked myogenic potential and Ocular vestibular evoked myogenic potential in 23 normal hearing individuals and 23 with bilateral severe to profound hearing loss. Results showed that the amplitude of cVEMPs and oVEMPs were abnormal in the hearing impaired group compared to normal hearing individuals. Also, the cVEMPs and oVEMPs are absent in few subjects with hearing loss compared to the normal hearing subjects indicating impairment of both utricular and saccular function in subjects with severe to profound hearing loss. Thus study concluded that there was more abnormality in oVEMP compared to cVEMP, suggesting that utricular function is more linked with the cochlea compared to that of the saccule.

Not only VEMPs but other tests such as rotational chair also reveal an abnormal test result when tested in children with bilateral sensorineural hearing loss. Maes et al., (2014), utilizing rotational chair testing and cervical vestibular testing, evaluated vestibular function in children with bilateral sensorineural hearing loss. Forty eight normally developing children without any vestibular or auditory complaints and thirty nine children diagnosed with bilateral sensorineural hearing loss were tested. Results demonstrated significant lower gain values for rotational chair testing and a greater percentage of absent cVEMP responses for children with hearing impairment compared to children with normal hearing sensitivity. Study concluded that there was some form of vestibular abnormality in hearing-impaired children. The authors highlighted the importance of vestibular evaluation in such children, vestibular evoked myogenic potential revealed an abnormal result also in adult participants diagnosed with sensorineural hearing loss similarly to that of children.

Kurtaran et al., (2016) evaluate the association between vestibular dysfunction and sensorineural hearing loss in adult patients. Sixty-three adult patients with hearing loss with or without any vestibular signs participated for the study. All the participants were tested for vestibular evoked myogenic potential (VEMP). Results of the study showed that in individuals with sensorineural hearing loss, both the latencies and the amplitudes of VEMP were abnormal. These findings indicated that vestibular weakness can accompany age-related sensorineural hearing loss without predisposing factors for vestibulopathy.

Caloric test, which is thought to be the standard test for assessment of the vestibular system, has also been seen to be abnormal in subjects with sensorineural hearing loss. Raj & Gupta (2017) administered monothermal warm air caloric test on 50 children diagnosed to have bilateral severe to profound sensorineural hearing loss. Forty-eight children successfully completed the test and the vestibular dysfunction was reported in 9 children, which was indicative of canal hypofunction. The authors also reported no significant correlation between compensated vestibular function outcomes with the degree of sensorineural hearing loss and age.

2.2 Head impulse paradigm test results in various vestibular pathologies

2.2.1 Benign Paroxysmal Positional Vertigo

Video head impulse test shows abnormal test results in individuals with benign paroxysmal positional vertigo. Chen et al. (2012) studied the dysfunction rate and characteristics of the semi-circular canal utilizing vHIT in individuals with BPPV. 214 subjects having benign paroxysmal positional vertigo (BPPV), which included 107 patients with posterior semi-circular canalithiasis, 80 subjects with horizontal semi-circular canalithiasis, 27 subjects with horizontal semi-circular canal cupulolithiasis underwent caloric tests (low frequency), head shaking tests (mid frequency) and high frequency vHIT tests. The results of the study revealed that this type of vertigo affects the low-frequency range of the frequency band of the semi-circular canal more than the high frequency. The authors concluded that, in the head shake nystagmus test and vHIT cannot be used for the assessment of BPPV.

Fallahnezhad et al., (2017) evaluated six semi-circular canals of individuals with BPPV utilizing Video head impulse test in 29 unilateral posterior canal-BPPV patients with healthy oculographic and caloric performance. The results of the study revealed an abnormal VOR gain in sixteen individuals with BPPV in the ipsilesional ear from the posterior canal whereas VOR gain values in other canals with no corrective saccades were within normal limits. The authors concluded that VOR gain in the posterior semi-circular canal may be reduced in patients with posterior canal-BPPV.

Cinar et al., (2018) identified the time course of changes in vHIT parameters in patients with posterior semi-circular canal BPPV during canalith repositioning maneuver. Twenty-four patients with posterior canal-BPPV and 20 age and gender-matched controls were recruited for the study. Fourteen patients in the BPPV group had right ear involvement, while ten patients had left ear involvement. In the BPPV group before and shortly after the Canalith repositioning maneuver, vHIT was performed for the affected posterior canal during the first visit to assess all canals. On the third and seventh day and one month after the first visit, subsequent vHIT procedures were administered and VOR gains and gain asymmetry were measured before and after Canalith repositioning maneuver. VOR gain and gain asymmetry values for the affected posterior canal were not statistically different before and after repositioning maneuver and during the 3rd, 7th and

1st-month visits. The values obtained for BPPV group and control groups were not significantly different, and none of the subjects showed corrective saccades. They concluded that vHIT may not provide additional information during the diagnosis and treatment of isolated posterior canal-BPPV to determine vestibular dysfunction.

Aslan et al (2018) evaluated forty nine patients, and by administering Dix–Hallpike test, thirty participants were diagnosed with vertical canal BPPV, and remaining 19 were had lateral canal BPPV which was confirmed using the Roll test. Patients were assessed based on the presence of saccades and vestibular ocular reflex gain obtained by assessing all semi-circular canals. VOR gain was normal for 17 patients. Reduced VOR gain was obtained for the vertical canal in 20 patients and in the lateral canal for 12 patients based on the VHIT findings. In 20 patients with canal dysfunction, saccades were observed. Hence they concluded that this test could be used as a diagnostic test to support BPPV.

2.2.2 Vestibular neuritis

Patients diagnosed with vestibular neuritis provided abnormal results while administering a video head impulse test. Manzari et al., (2013) examined two patients, one male and one female, both aged 36 and diagnosed with right-sided vestibular neuritis. None of the patients recruited for the study were having Meniere's disease or cochlea or labyrinthitis involvement as no specific symptoms were present. The vHIT presented a distinctly impaired right horizontal VOR gain for both patients and the standard VOR gain for the left (the better side). Regular retesting was carried out following the initial evaluation, in order to assess the time of recovery from acute neuritis based on the dynamic VOR. In the first case- male there was a complete recovery of horizontal canal function, whereas in the second case- female there was a complete lack of horizontal canal function recovery. It indicates vHIT's clinical quality in testing vestibular neuritis patients. A very useful information about the vestibular compensation can be obtained using vHIT test and also highlights the seeming value of covert vestibular compensation saccades.

Blödow et al., (2013) conducted a study to examine horizontal VOR in peripheral vestibular disorders using vHIT. One hundred seventeen patients diagnosed having vestibular disorders and 20 healthy subjects were selected and tested using vHIT and their horizontal VOR gain was noted. The patient group included 52 subjects with unilateral vestibular neuritis, 31 subjects with a vestibular schwannoma, 22 with Meniere's disease, and 12 bilateral vestibulopathy patients. A normal vHIT was found in 3 patients with vestibular neuritis, and an abnormal vHIT was found in 49 of them. In vestibular neuritis cases, the vHIT was mostly abnormal with a strong reduction in hVOR gain along with the presence of refixation saccades at the affected side.

Bartolomeo et al., (2014) evaluated the output of video head impulse test in the diagnosis of vestibular neuritis. At the initial and follow-up examination, 29 patients diagnosed with vestibular neuritis underwent caloric and vHIT testing. Complete recovery occurred at the time of follow-up visit in 31% of cases according to caloric assessment and in 51.8% vHIT was normalized. All acute cases of vestibular neuritis were detected correctly by vHIT, and this showed the specificity and appropriate sensitivity of VHIT. Vestibular recovery assessment could be achieved using vHIT. vHIT is a simple and precise test for detecting vestibular problems. Nonetheless, compared to caloric testing, vHIT lacks sensitivity, especially for less severe vestibular lesions.

The video head impulse test reliably measures variations in the upper frequency range (5–7 Hz) of the vestibular eye reflex in all the three planes and it is also useful in assessing the dysfunction of semi-circular canals. A study was conducted by Walther and Blödow (2013) to test oVEMP and cVEMP and to compare the response with vHIT findings in acute unilateral vestibular neuritis (VN) in order to determine the possible participation of semi-circular canals and otolith organs. oVEMP and cVEMP (tone burst stimulation of 100 dBnHL 500 Hz) were recorded in patients with vestibular neuritis, and vHIT was performed at all three planes. The results of this study indicated that in most cases with entire, superior, and inferior vestibular neuritis, the oVEMP and cVEMP results followed the expected trend of functional impairment of vHIT, but not in isolated ampullary neuritis (AVN). Thus, vHIT can be used in conjunction with oVEMP and cVEMP, enabling a more accurate differential diagnosis (entire, superior, inferior, and ampullary vestibular neuritis) of vestibular function (partial or complete dysfunction) in patients with acute unilateral vestibular neuritis.

Mantokoudis et al. (2015) reported the values of the vestibulo-ocular reflex in vestibular neuritis and stroke with the acute vestibular syndrome (AVS). Horizontal head impulse test were performed, and gain values of VOR was obtained from 26 patients with the acute vestibular syndrome. Within one week of symptom onset, all patients were assessed. Vascular territory classified brainstem and cerebellar strokes as posterior inferior cerebellar artery (PICA) or anterior inferior cerebellar artery (AICA).Vestibular neuritis was diagnosed in 16 patients and posterior fossa stroke in 10 patients. VOR gains in neuritis (unilateral vestibulopathy) and PICA stroke (normal bilateral VOR) were asymmetric, while AICA stroke gains were asymmetric and low. The peripheral and central causes of stroke vary in video HIT vestibulo ocular reflex gains values PICA strokes were easily separated from vestibular neuritis, but AICA strokes were at risk of misclassification based on VOR gain alone.

Yoo et al (2016) studied the caloric and vHIT outcomes in 36 individuals having vestibular migraine (VM) and 23 having vestibular neuritis (VN). The response to higher frequency head movements were evaluated with Video head impulse test and lower frequency head movements were evaluated with caloric test to assess the functioning of lateral canal. An abnormal canal paresis and a significant gain asymmetry (GA) were seen in patients with VN, and this was reduced in patients with vestibular migraine. The findings of the study suggest that patients with vestibular migraine had considerable residual lateral canal function, especially for higher frequency stimuli (for vHIT). So it can be concluded that both caloric and vHIT outcomes are more often affected in vestibular neuritis (VN), than vestibular migraine. Both caloric and vHIT investigate different range of frequencies and they provide complementary information regarding the functioning of lateral semicircular canal.

2.2.3 Meniere's Disease

The outcomes of caloric test and video head impulse test in were compared between individuals having Meniere's disease and vestibular migraine by Blodow et al (2014). The mean VOR gain obtained for both the group on the impaired side was lower than on the unaffected side and found to be more severe in Meniere's Disease patients than in Vestibular Migraine patients. The caloric results in both groups were negatively associated with vHIT findings and hence frequency dependent VOR impairment identification was recommended. That is both caloric and vHIT tests together.

A case study was done by Yacovino et al., (2017) in which a 64 year old patient diagnosed having unilateral Meniere’s disease was evaluated during and after the vertigo attack. A video head impulse test was carried out to obtain dynamic vestibulo-ocular reflex (VOR) in both stages of vertigo. The greatest decline in VOR gain was found in the impaired side when tested during the attack, and VOR gain returned to normal value once the patient was tested after the attack. Hence vHIT can be considered as the tool to document vestibular fluctuation during and after the attack in Meniere's disease.

Another study was done by Rubin et al. (2018) to compare VHIT and caloric reflex test results in advanced unilateral definite Meniere’s disease. Normal VHIT results were obtained for all patients recruited for the study and also 3 of the participants had normal caloric reflex. Thus they concluded that VHIT was normal during advanced unilateral definite Meniere’s disease, even though there was a presence of abnormal caloric reflex.

2.2.4 Semicircular canal dehiscence

An abnormal vestibulo ocular reflex gain values were obtained when patients with semi-circular dehiscence were tested with the head impulse paradigm. Manzari, Burgess, MacDougall & Curthoys (2011) have done a case study of a 55-year-old female primary school teacher diagnosed having semi-circular canal dehiscence. The complained put forward by the individual was the presence of an irritating and pulsatile tinnitus in both ears on changing head position and she also had a history of Tullio phenomenon. The video head impulse test was used for assessing the function of each canal. The catch-up saccades were found while administering vHIT in the plane of both anterior semi-circular canals was a clear suggestion of the bilaterally lacking VOR function of the semi-circular canal.

Patients with semi-circular canal dehiscence, when tested with vestibular evoked myogenic potentials, gave abnormal results but video head impulse test gave a normal result in the same population. A case study was done by Manzari et al., (2015) in which they evaluated all peripheral vestibular sense organs of a 58-year-old female diagnosed having superior semi-circular canal dehiscence. The function of semicircular canals using video head impulse test and otolith organs using both cVEMP and oVEMP were assessed. All semi-circular canals showed normal function as they revealed VOR gain within the normative range and absence of refixation saccades. The cVEMPs revealed improved, but symmetrical saccular function and oVEMPs revealed an improved but asymmetric or decreased function in the right utricle.

2.2.5 Vestibular Schwannoma

Two different tests used to assess the vestibular function are caloric test, and video head impulse test, and both the test results obtained were abnormal in case of vestibular schwannoma. Patients with unilateral vestibular schwannoma were studied by Blödow et al., (2015). Caloric testing and video head impulse testing were administered in 69 patients. The caloric test reveals low-frequency horizontal VOR gain, and vHIT reflects high-frequency horizontal VOR deficiencies. Generally the entire frequency range of horizontal VOR function can worsen in Vestibular Schwannoma but the results of the study specify that the lower frequency is more affected, whereas the higher frequency is preserved. Also, tumor grade of vestibular schwannoma has an effect on caloric test results but not on vHIT. Hence the combination of both tests allows the interpretation of horizontal VOR impairment in a range of frequency.

Both cervical and ocular vestibular evoked myogenic potential were tested in subjects with vestibular schwannoma and it found to be abnormal. Taylor et al., (2015) studied 50 subjects with a definite diagnosis of unilateral vestibular schwannoma. A 5-item test battery consisting of AC cVEMPs, BC oVEMPs, and video head impulse testing (vHIT) in all three canal planes were done for the assessment of vestibular dysfunction in subjects with vestibular schwannoma. All the tests were found to be abnormal in this case. The test result of vHIT mean VOR gain was significantly lower on the impaired side for all the semicircular canals. The vHIT gain of horizontal canal demonstrated the strongest relationship with tumor size. In the presence of large tumors a lower horizontal vHIT gain was obtained. Hence video head impulse test can be considered as a tool in diagnosing vestibular schwannoma.

Tranter et al., (2016) assessed 30 participants diagnosed with unilateral Vestibular schwannoma. Both caloric and video head impulse test were done for all participants. The results showed an abnormal canal paresis in twenty patients and only ten patients had reduced vHIT gain. Also, they concluded that tumor dimensions could be predicted from ipsilesional vHIT gain as well as canal paresis and thus provide better sensitivity of the tests.

2.3 Suppression head impulse paradigm

Suppression head impulse paradigm is a procedure that assesses the function of semi-circular canals in which presence of anticompensatory saccades are considered normal. This test revealed an abnormal result when tested various vestibular pathologies.

Kang et al., (2017) analyzed the effects of the paradigm of suppression head impulse in 24 subjects, which includes healthy individuals, patients with vestibular neuritis, benign paroxysmal positional vertigo, Meniere's disease, loss of bilateral vestibular capacity and acoustic schwannoma. SHIMP testing revealed high sensitivity and precision in patients with vestibulopathy. Patients suspected of BPPV, vestibular neuronitis, and Meniere's disease demonstrated reduced vestibulo ocular reflex gain and decreased anticompensatory saccade relative to healthy people. This proved the feasibility of the SHIMP test to detect the pathological state of VOR in patients with vestibulopathy.

Both HIMP and SHIMP were tested in individuals diagnosed with vestibular neuritis and both were found to be abnormal. Chen et al., (2018) studied the participation of suppression head impulse paradigm in assessing vestibular neuritis. Twenty patients were evaluated with both test procedures. Refixation saccades were elicited in the affected side, and no saccades in the healthy side was obtained in HIMP testing. Whereas in SHIMP, healthy side elicited anti-compensatory saccade and affected side with no compensatory saccade. The gain derived for HIMP was larger than those of SHIMP in both the affected and healthy side. And they concluded that suppression head impulse paradigm can be used to evaluate vestibular function and residual retention in vestibular neuritis, and can also to monitor vestibular compensation in patients dynamically.

A comparison of vestibular ocular reflex gain values obtained through video head impulse test and suppression head impulse paradigm was done by Netz et al., (2018) in 35 patients diagnosed with unilateral Meniere’s disease without acute vertigo attack. VOR gain values for both affected and unaffected side were obtained and it was found that suppression head impulse paradigm had somewhat better VOR gain difference between impaired and normal side compared to the values of video head impulse test. And thus, SHIMP was considered to be a useful diagnostic tool in addition to the vHIT**.**

Devantier et al., (2018) tested 29 healthy adolescents using head impulse paradigm and suppression head impulse paradigm. Vestibular ocular reflex gain values and presence or absence of refixation saccades were noted. Both covert and overt saccades were absent in the head impulse paradigm, whereas anti compensatory saccades were found in suppression head impulse test. The gain values of SHIMP were lower than the gain values of HIMP. The study provides the sensitivity of the particular examination.

Eighty healthy subjects were evaluated by Rey-Martinez et al., (2018) using head impulse paradigm and suppression head impulse paradigm, and vestibular ocular reflex gain obtained using both tests were compared. A difference was seen in the gain values obtained through both tests. Slight but lower gain values were obtained through the Suppression head impulse paradigm.

Video head impulse test is used to assess the function of all three semi-circular canals and this test provides an abnormal result in case of adults having sensorineural hearing loss. Sinha & Bansal (2017) assessed the functioning of canals in those with severe to profound sensorineural hearing loss. Twenty adult participants in Group I with severe to profound hearing loss and group II consisted of 20 adult participants with normal hearing sensitivity were tested. In people with hearing impairment, the average VOR gain values in the right and left horizontal canals, right anterior and left posterior canals are smaller than those with hearing sensitivity within normal limits. And the conclusion of the study was that vestibular abnormality was seen in people with severe to profound hearing loss. Hence, they recommended that for the assessment of individuals with severe to profound sensorineural hearing loss, the vestibular tests should be included in the diagnostic test battery.

Yu and Li (2018) reported that the assessment of vestibular function in sensorineural hearing loss could be of high relevance. To confirm this, they investigated the prevalence of sudden sensorineural hearing loss in which vestibulocochlear lesions are there and its correlation with the hearing prognosis of specific vestibular organs. Research which concentrated on vestibular analysis in the case of sensorineural hearing loss involving caloric tests, cervical vestibular-evoked myogenic potential (cVEMP) tests, or oVEMP tests was collected. Results of these studies revealed that in sensorineural hearing loss, the most frequently affected vestibular organ was utricle followed by the lateral semi-circular canal and then the saccule. This study also demonstrates the relevance of concomitant vestibular damage to sensorineural hearing loss.

In the review of literature, authors are found to be utilizing video head impulse test for the diagnosis of various vestibular pathologies such as vestibular neuritis, Meniere's disease, vestibular schwannoma etc. As there is a lack of research of vestibular impairment in different degrees of sensorineural hearing loss, this study has been taken up by utilizing the video head impulse test.

Chapter-III

Method

The present study aims to study VOR gain values using Head Impulse Paradigm and Suppression Head Impulse Paradigm in older adults. To achieve the aim, the individuals recruited for the study were divided into two different groups. Group, I comprised of 30 participants (15 males and 15 females) within the age range of 40-70 years. Group II included 30 participants (15males and 15 females) within the age range of 18-40 years.

3.1 Participant selection criteria

Group I

1. The participants in the present group had sensorineural hearing loss.
2. Participants with a positive history of middle ear disorders such as ear discharge, ear pain, etc, and history/presence of any conductive/mixed hearing loss were excluded from the study.
3. Participants did not have the presence of any sort of vestibular disorders, including Vestibular neuritis, Labyrinthitis, Meniere's disease, BPPV etc.
4. Participants did not have the presence of any retrocochlear pathology.
5. Participants did not have the presence of cervical spondylitis.

Group II

1. The participants in the present group had sensorineural hearing impairment.
2. The participants did not have any middle ear problems or any conductive pathology.

3. Participants didn't have any vestibular related complaints or any history of vestibular dysfunction
4. None of them had any history/presence of spondylitis.
5. Participants did not have the presence of any retrocochlear pathology

3.2 Instrumentation

- A calibrated audiometer Inventis Piano with TDH-39 headphones, housed in MX-41/AR (Telephonics, Farmingdale, NY, USA) ear cushions was used to track the pure tone audiometry thresholds and administer speech audiometry among all participants. Radio ear B71 bone transducer (Radio ear, KIMMETRICS, smithsburgh, Maryland, USA) headset was used to estimate the threshold for bone conduction.
- Middle Ear Analyzer Gradson- Stadler Incorporated (GSI) Tympstar (GSI VIASYS Healthcare, WI,USA) was used to obtain the tympanogram pattern, peak static admittance, tympanometric peak pressure, equivalent ear canal volume and acoustic reflex threshold in each of the selected participants.
- Biologic Navigator Pro version 7.2 (Natus Medical incorporated, San Carlos, CA, USA) was utilized for recording the auditory brainstem responses to rule out the retrcocohlear pathology.
- Head impulse test paradigm and Suppression head impulse paradigm was done using ICS Impulse OTOsuite vestibular software version 1.2 (GN Otometrics, Denmark).

3.3 Procedure

3.3.1 Case History

A detailed case history was obtained from all the participants. The questions included were concerning the presence/ absence of conductive symptoms, history of any middle ear pathology, and medications underwent. Questions regarding the presence of any vestibular symptoms such as vertigo, imbalance, unsteadiness, nausea/ vomiting, blurring of vision were incorporated. Questions involved revealed the history/presence of diabetes, hypertension, and other neurologic disorders. The case history also included questions answering the symptoms of retrocochlear pathology.

3.3.2 Pure tone Audiometry

Pure tone audiometry was carried out, and hearing thresholds from all the participants were obtained using a modified version of Hughson and Westlake procedure (Carhart&Jerger, 1959) at all octave frequencies between 250 Hz to 8000 Hz for air conduction and between 250 Hz to 4000 Hz for bone conduction.

3.3.4 Immittance

Tympanogram was acquired using 226 Hz probe tone in both ears and acoustic reflex thresholds were estimated for both ipsilateral and contralateral recording using 500, 1000, 2000 and 4000Hz stimulus.

3.3.5 Auditory Brainstem Response

ABR-Site of lesion testing was done using clicks at 90 dBnHL.Electrodes were placed at Fz, M1, M2, and Fpz position. Electrode impedance of 5 KΩ or less than that was considered. ER-3A insert earphone was used to present the stimulus. A repetition rate of 11.1/s followed by 90.1/s was used. A band pass filter of 100 to 3000Hz and 2000 sweeps were used and recorded for a 12ms time window. Each recording was repeated to ensure the replication of the responses.

3.3.6 Video Head Impulse test

The two vHIT explorations, which are HIMP and SHIMP, were carried out respectively in each participant according to the protocol to assess the vestibular function of the lateral semi-circular canal in all participants.

3.3.6.1 Head impulse (HIMP) paradigm: HIMP protocol was performed on the subject in consideration seated on the chair such that he/she is facing the wall at a distance of 1 meter. The vHIT goggles were positioned over the participant's eyes, and the headband was tightened so that glasses do not slip even slightly during the rapid head movements. Then a laser beam will be switched on which projects two laser dots on the wall. A target/dot is fixed right between the two laser dots, which are in the participant's line of sight. Then calibration of the instrument was carried out before the actual test. Now laser dot appeared alternatively at either side of the target/dot at an angle of 10 degrees. The participant was asked to follow the laser dot wherever it appears. No head impulse was initiated for calibration. Once calibration is done actual test was carried out, and now the laser dots will no longer be present on the wall. The instruction was given to the participant to sustain his/her gaze at the target/dot on the wall during the entire procedure. Twenty abrupt, unpredictable, and brief head impulses were manually applied towards the left and right side (yaw plane) randomly to stimulate the horizontal semi-circular canal. The extent of head rotation was about 10 degrees from starting position, and peak head velocity of the impulse was of 150 degrees/sec.

3.3.6.2 Suppression head impulse paradigm (SHIMP): Another test paradigm of HIMP is known as SHIMP. The SHIMP protocol followed exactly the same procedure as that of HIMP with only one variation in the fixation of the target. The participant was seated in front of the wall 1 meter away with the goggles positioned over the eyes. Before the actual test, the calibration of the instrument was done, which incorporates the same calibration procedure as in HIMP. Once it is done the earlier fixed target/dot was removed from the wall and the participant was instructed to follow the red laser dot projected on to the wall which is directed from the goggles which moved with head, jerky head movements were imposed towards the right and left at an angle about 10 degree. The head impulses imposed were brief, abrupt, and unpredictable so that the patient does not present an early eye movement guessing the direction of head movement along the yaw plane. Twenty head impulses with similar peak head velocity were imposed to each side as in HIMP protocol.

Data Analyses

After data acquisition, the VOR gain values in lateral planes for both Head Impulse Paradigm and Suppression Head Impulse Paradigm were used for the analyses. The values obtained were compared between both younger and older males and female participants to identify the difference in VOR gain, if any. The presence of refixation saccades during both HIMP and SHIMP were also analyzed for both younger and older adults.

Chapter-IV

Results

The study was conducted to assess the VOR gain values using Head impulse paradigm and suppression head impulse paradigm in older and younger adults. To achieve the aim, 30 older adults (15 male; 15 female) and 30 younger adults (15 male; 15 female) subjects participated in the study. All individuals underwent Video head impulse testing (vHIT) and were evaluated based on the mean VOR gain values and presence/ absence of saccades and anticompensatory saccades in HIMP and SHIMP protocol.

4.1 Vestibuloocular reflex (VOR) gain with HIMP and SHIMP paradigm

4.1.1 Head Impulse Paradigm

Head impulse paradigm (HIMP) testing was administered for all the 60 participants (both group I and group II). VOR gain was calculated for all the participants only in their lateral plane. Also, for all the participants, the presence or absence of corrective saccades was noted.

Representative waveforms of HIMP obtained for group I (older adults) and group II (younger adults) of both the genders are shown in Figure 4.1, Figure 4.2, Figure 4.3 and Figure 4.4.

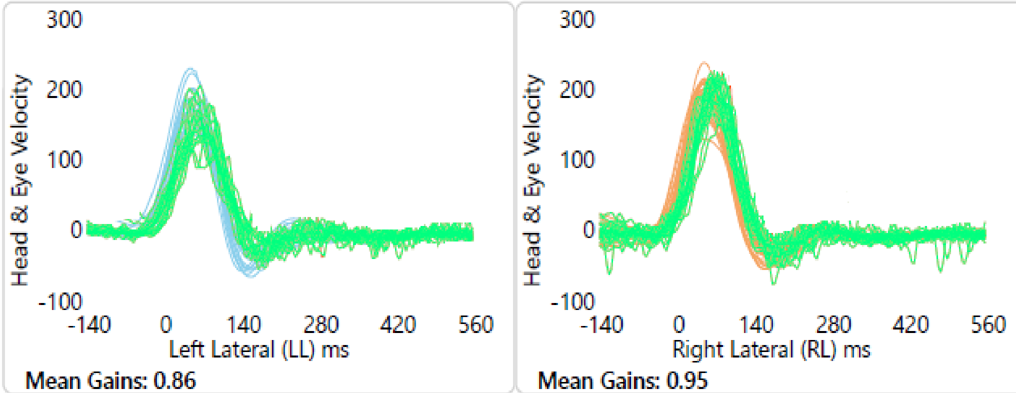

Figure: 4.1. *HIMP test results in lateral plane in one of the male in older adult group.*

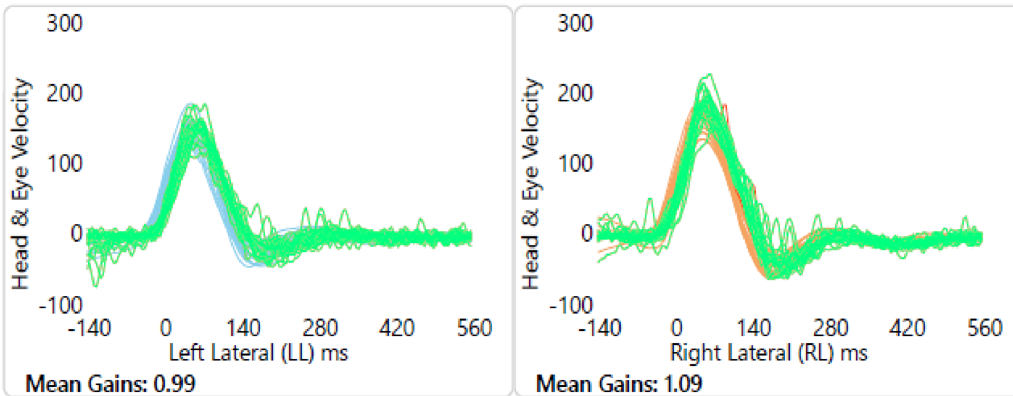

Figure: 4.2. *HIMP test results in lateral plane in one of the female in older adult group*

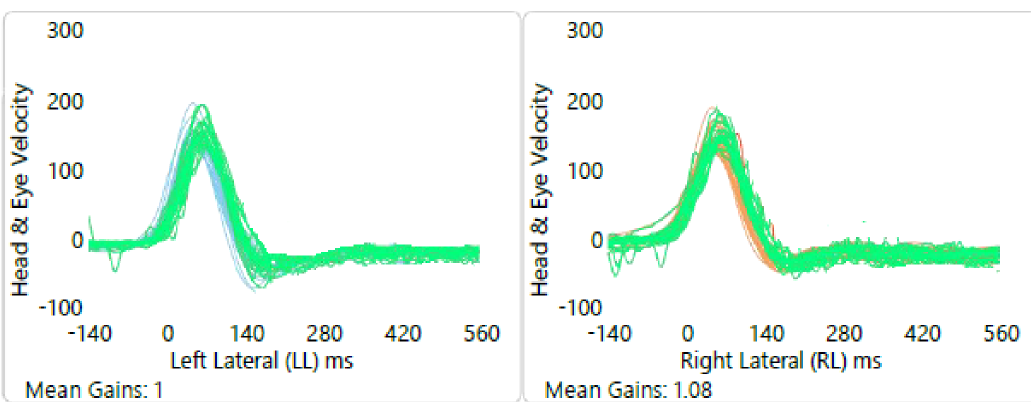

Figure: 4.3. *HIMP test results in lateral plane in one of the male in younger adult group.*

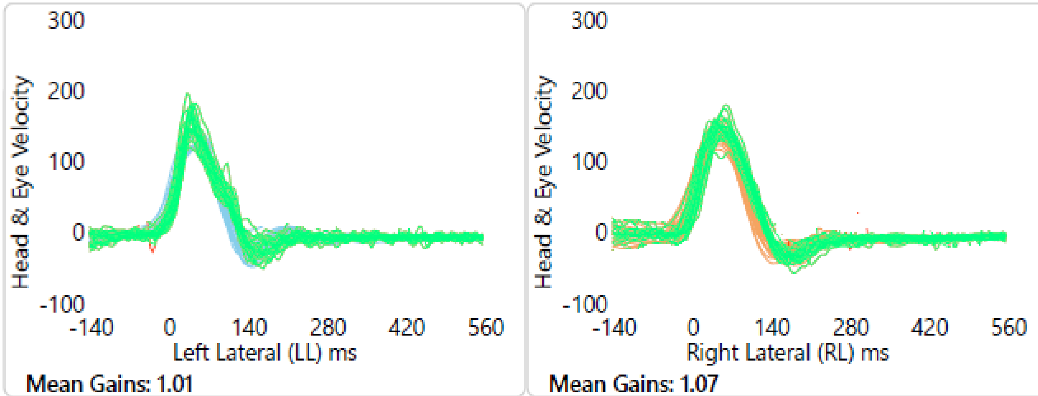

Figure: 4.4. *HIMP test results in lateral plane in one of the female in younger adult group.*

4.1.2 Suppression Head Impulse paradigm (SHIMP)

All 60 participants recruited for the testing were tested with suppression head impulse paradigm in their lateral planes. The test outcomes were analyzed. The presence of anticompensatory saccade was considered as normal SHIMP response and the absence of the same as abnormal. Also, the VOR gain for all the participants was calculated using the SHIMP protocol.

Representative waveforms of VOR gain with SHIMP techniques in participants in group I (older adult) and group II (younger adult) of both genders are shown in figure 4.5, Figure 4.6, Figure 4.7 and Figure 4.8.

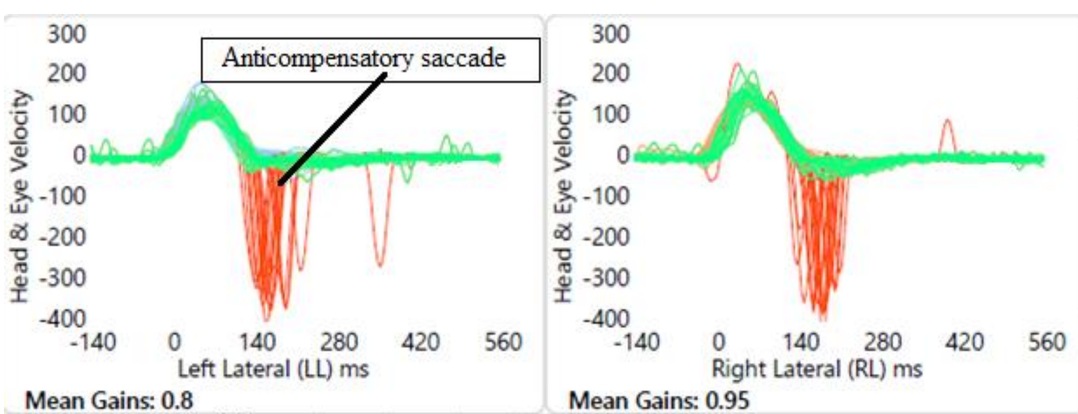

Figure: 4.5. *SHIMP test results in lateral plane in one of the male in older adult group.*

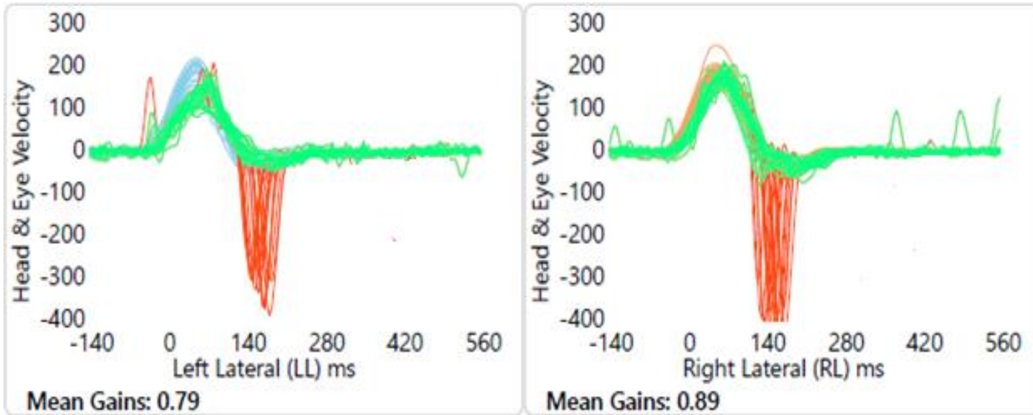

Figure: 4.6. SHIMP *test results in lateral plane in one of the female in older adult group.*

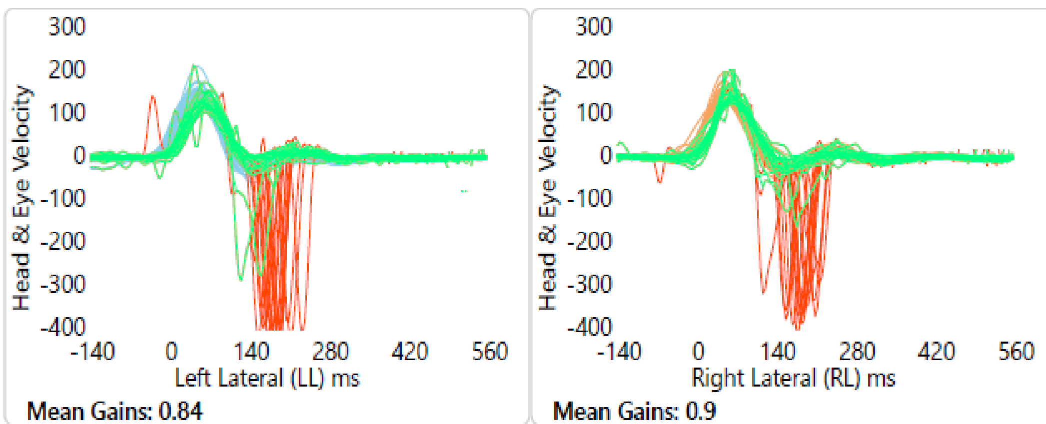

Figure: 4.7. *SHIMP test results in lateral plane in one of the male in younger adult group.*

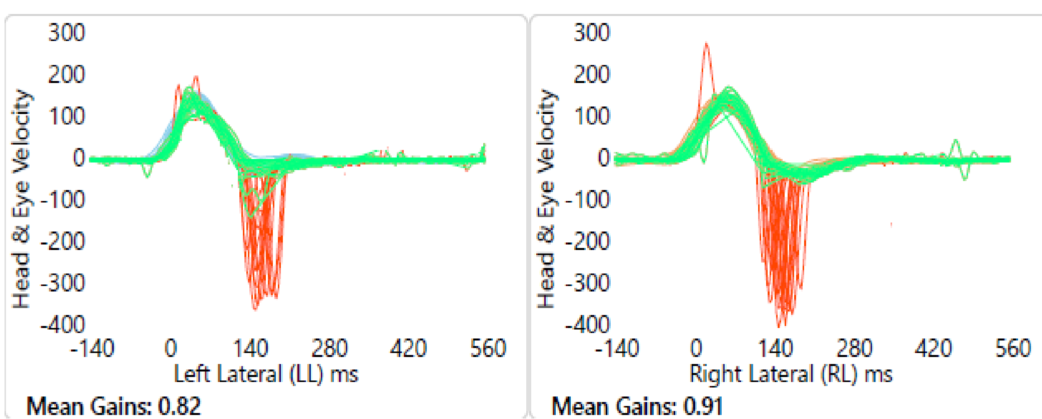

Figure: 4.8. *SHIMP test results in lateral plane in one of the female in younger adult group.*

Shapiro Wilk test was done to check the normality distribution of the data. Shapiro Wilk test revealed a normal distribution of the data for both the groups ($p>0.05$). Descriptive statistics was done to find out the mean and the standard deviation for the VOR gain using the Head impulse paradigm and Suppression head impulse paradigm. The mean and standard deviation of VOR gain using HIMP and SHIMP techniques in older adults and younger adults are shown in Table 4.1.

Table: 4.1.

Mean and Standard Deviation of the VOR gain using HIMP and SHIMP techniques for right and left ear for both the Older adult group and Younger adult group.

		Right ear VOR gain			**Left ear VOR gain**		
		N	Mean	SD	N	Mean	SD
Older adult (Group I)	HIMP	30	0.98	0.07	30	0.88	0.09
	SHIMP	30	0.76	0.12	30	0.70	0.08
Younger adult (Group II)	HIMP	30	1.09	0.13	30	1.02	0.14
	SHIMP	30	0.94	0.12	30	0.86	0.11

It can be seen from Table 4.1 that the mean VOR gain for younger adults is higher compared to the mean VOR gain in older adults for both the HIMP and SHIMP paradigm. It can also be seen from Table that the mean VOR gain using the HIMP paradigm is higher compared to the mean VOR gain using the SHIMP technique for both the groups. It can also be seen that the mean VOR gain for the right ear is more compared to the left ear for both the groups using both HIMP and SHIMP technique. The same can be seen in Figure- 4.9

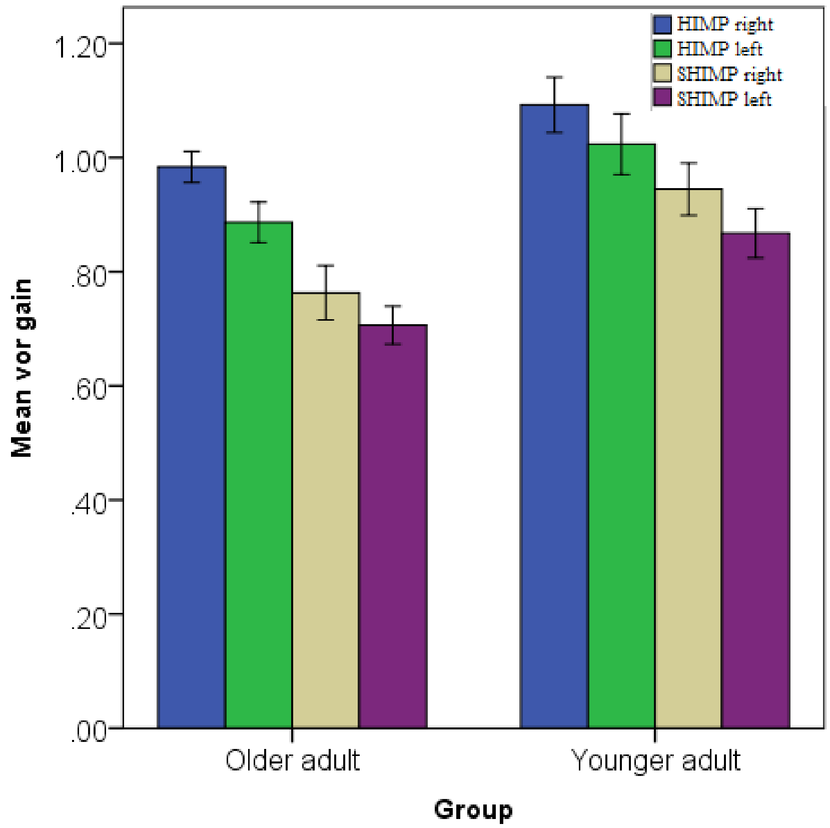

Figure: 4.9. *VOR gain values of HIMP and SHIMP in the older adult and younger adults.*

To understand the significant differences in the mean VOR gain values between younger and the older adults using the HIMP and SHIMP paradigm, an Independent sample T test was done. The results of the independent sample t-test are shown in Table 4.2.

Table: 4.2.

Independent Sample T-Test values obtained after comparing Mean VOR gain between group I and group II for HIMP and SHIMP test.

		T	df	Sig. (2-tailed)
HIMP	Right ear	3.98	58	0.00
	Left ear	4.37	58	0.00
SHIMP	Right ear	5.63	58	0.00
	Left ear	6.05	58	0.00

The result of the independent sample t-test showed that there was a significant difference in HIMP and SHIMP VOR gain values between younger and older adults. The mean VOR gain values for younger adults are higher compared to the older adults for both the HIMP and SHIMP technique for both the ears.

To understand at what age the VOR gain starts to decline, the older groups were subdivided into three groups. Subgroup I consisted of participants in the age range of 40-50 years, subgroup II consisted of participants in the age range of 51-60 years, and subgroup III consisted of participants in the age range of 61-70 years. The mean VOR values for the three groups are shown in table 4.3 below.

Table: 4.3.

Mean and Standard Deviation of the VOR Gain using HIMP And SHIMP techniques for right and left ear for three subgroups of the Older adult group.

		Right ear VOR gain		**Left ear VOR gain**	
		Mean	SD	Mean	SD
HIMP	Young adult	1.09	0.13	1.02	0.14
	Subgroup I	0.98	0.07	0.84	0.11

	Subgroup II	1.01	0.05	0.91	0.05
	Subgroup III	0.95	0.08	0.91	0.07
SHIMP	Young adult	0.94	0.12	0.86	0.11
	Subgroup I	0.76	0.12	0.69	0.10
	Subgroup II	0.80	0.11	0.73	0.08
	Subgroup III	0.71	0.13	0.70	0.06

It can be seen from Table 4.3 that the mean VOR gain obtained using HIMP paradigm is higher compared to the mean VOR gain obtained using the SHIMP paradigm for both right and left ear. Also, the mean VOR gain values for younger adults are much higher when compared to mean VOR gain values of three subgroups of older adults for both HIMP and SHIMP.

Further to compare significant differences in the mean values of HIMP and SHIMP VOR gain between the three subgroups of the older individuals and younger individuals for both right and left ear, the multivariate analyses of variance (MANOVA) were done. Multivariate analyses of variance revealed a significant main effect for VOR gain values for HIMP right [$F(3, 56) = 5.64$, $p<0.05$], HIMP left VOR gain [$F(3, 56) = 7.20$, $p<0.05$], SHIMP right VOR gain [$F(3, 56) = 11.28$, $p<0.05$] and SHIMP left VOR gain [$F(3, 56) = 12.16$, $p<0.05$].

To understand the significant difference between the different subgroups in older individuals group and younger adults, Duncan's post hoc analyses was done. Duncan's Post hoc analysis results are tabulated in Table 4.4.

Table: 4.4.

Duncan's Post Hoc Analyses values for a significant difference in VOR gain values between the three subgroups of Older adults and the Younger participants

VOR gain	**Groups**	**2**	**3**	**4**
HIMP right	**1**	P<0.05	P>0.05	P<0.05
	2		P>0.05	P<0.05
	3			P>0.05
HIMP left	**1**	P<0.05	P<0.05	P<0.05
	2		P<0.05	P<0.05
	3			P<0.05
SHIMP right	**1**	P<0.05	P<0.05	P<0.05
	2		P<0.05	P<0.05
	3			P<0.05
SHIMP left	**1**	P<0.05	P<0.05	P<0.05
	2		P<0.05	P<0.05
	3			P<0.05

The result of Duncan's post hoc test revealed that there was a significant difference in VOR gain values between younger adults and three subgroups of older adults using the HIMP and SHIMP technique. The VOR gain for the younger adult group was higher compared to all the subgroups of older adults ($p<0.05$) except between the younger adult group and in the older group of 51-60 years (subgroup II) using HIMP technique for the right ear. This implies that the VOR gain started to decline at 40 years of age for the older adult group.

4.1.3 Comparison of VOR gain between HIMP and SHIMP paradigm

Paired sample t-test, test for normality was performed to compare the VOR gain between older adults and younger adults for both HIMP and SHIMP technique. The data of paired sample t-test is shown in Table 4.5.

Table: 4.5.

Paired Sample T-Test values obtained after comparing right ear and left ear of Group I with right ear and left ear of Group II participants.

		T	**df**	**Sig (2- tailed)**
Group I (Older adult)	Right ear	8.65	29	0.00
	Left ear	9.91	29	0.00
Group II (Younger adult)	Right ear	9.74	29	0.00
	Left ear	6.77	29	0.00

The result of the paired sample t-test showed that VOR gain for both the right ear and left ear was statistically different between the younger adult group and the older adult right and left ear in both older adults and younger adults group.

4.2 Association of VOR gain with the degree of hearing loss

To find the association between HIMP, SHIMP VOR gain of right and left ear and degree of hearing loss of right and left ear of participants of group I and group II, chi-square test was performed. Table 4.6 shows the details of the participants hearing loss.

Table: 4.6.

Details of the participant's Hearing Loss

Subject	**Age**	**Gender**	**Degree of hearing loss**
Sub 1	62	M	Mild
Sub 2	55	M	Mild
Sub 3	58	M	Moderate
Sub 4	70	M	Moderately severe
Sub 5	47	M	Profound
Sub 6	49	M	Profound
Sub 7	42	M	Severe
Sub 8	43	M	Severe
Sub 9	49	M	Severe
Sub 10	46	M	Moderate
Sub 11	43	M	Moderately severe
Sub 12	41	M	Mild
Sub 13	66	M	Mild
Sub 14	52	M	Moderate
Sub 15	53	M	Moderately severe
Sub 16	44	F	Profound
Sub 17	65	F	Moderately severe
Sub 18	61	F	Severe
Sub 19	57	F	Mild
Sub 20	63	F	Moderately severe
Sub 21	50	F	Moderate
Sub 22	40	F	Mild
Sub 23	54	F	Moderately severe
Sub 24	67	F	Severe
Sub 25	41	F	Moderately severe
Sub 26	51	F	Moderately severe
Sub 27	42	F	Moderate
Sub 28	70	F	Moderately severe
Sub 29	65	F	Moderate
Sub 30	47	F	Mild
Sub 31	24	M	Moderate

Sub 32	21	M	Profound
Sub 33	34	M	Mild
Sub 34	30	M	Moderate
Sub 35	33	M	Moderate
Sub 36	30	M	Mild
Sub 37	29	M	Mild
Sub 38	31	M	Mild
Sub 39	33	M	Profound
Sub 40	29	M	Moderate
Sub 41	35	M	Moderate
Sub 42	31	M	Mild
Sub 43	25	M	Mild
Sub 44	35	M	Mild
Sub 45	29	M	Mild
Sub 46	19	F	Profound
Sub 47	27	F	Moderate
Sub 48	25	F	Profound
Sub 49	28	F	Mild
Sub 50	34	F	Moderate
Sub 51	35	F	Mild
Sub 52	22	F	Moderate
Sub 53	35	F	Moderately severe
Sub 54	39	F	Mild
Sub 55	26	F	Mild
Sub 56	20	F	Mild
Sub 57	22	F	Mild
Sub 58	35	F	Moderately severe
Sub 59	31	F	Mild
Sub 60	27	F	Moderate

Table 4.7 shows the chi-square value for the association between the degree of hearing loss and HIMP, SHIMP VOR gain of both right and left ear in older adults.

Table: 4.7.

Association between the degree of hearing loss and HIMP, SHIMP VOR gain of both right and left ear in Older adults.

		df	Asymp.Sig. (2 sided)
Right ear	HIMP	76	0.40
	SHIMP	84	0.24
Left ear	HIMP	68	0.17
	SHIMP	72	0.20

Table 4.8 shows the chi-square value for the association between the degree of hearing loss and HIMP, SHIMP VOR gain of both right and left ear in younger adults

Table: 4.8.

Association between the degree of hearing loss and HIMP, SHIMP VOR gain of both right and left ear in Younger Adults.

		df	Asymp.Sig. (2 sided)
Right ear	HIMP	38	0.39
	SHIMP	42	0.55
Left ear	HIMP	57	0.05
	SHIMP	57	0.78

The result of chi-square test shows that there is no association between the degree of hearing loss of right and left ear and VOR gain measured using HIMP and SHIMP techniques of right ear and left ear. Hence it can be stated that the VOR gain of both HIMP and SHIMP is independent of the degree of hearing loss.

4.3 VOR gain Values comparison between male and female

Independent sample t-test was performed to compare the HIMP and SHIMP VOR gain between male and female participants. The data of the independent sample t-test is shown in Table 4.9.

Table: 4.9.

Independent Sample T-Test values obtained after comparing mean VOR gain of HIMP And SHIMP between male and female participants.

		T	**df**	**Sig (2- tailed)**
HIMP	Right ear	-0.51	28	0.60
	Left ear	-1.42	28	0.16
SHIMP	Right ear	0.26	28	0.79
	Left ear	-0.77	28	0.44

The result of the independent sample t-test showed that there was no significant difference in the HIMP and SHIMP VOR gain values when compared between male and female participants.

4.4 Analyses of presence/ absence of saccades in HIMP and SHIMP

HIMP response outcomes were analyzed, and it was found that all 60 participants considered for the study had their HIMP mean VOR gain within the normal range. And none of the participants had the presence of any corrective saccades and hence were considered to be normal.

When the SHIMP response outcomes were evaluated based on the presence or absence of anticompensatory saccade, 3 participants (1 male; 2 female) of older adult group had reduced anticompensatory saccade, which is considered as abnormal. Remaining 27 participants of the older adult group and 30 of the younger adult group had anticompensatory saccades and hence they were considered to be normal. Representative waveform of a participant with reduced anticompensatory saccade is presented in figure 4.10.

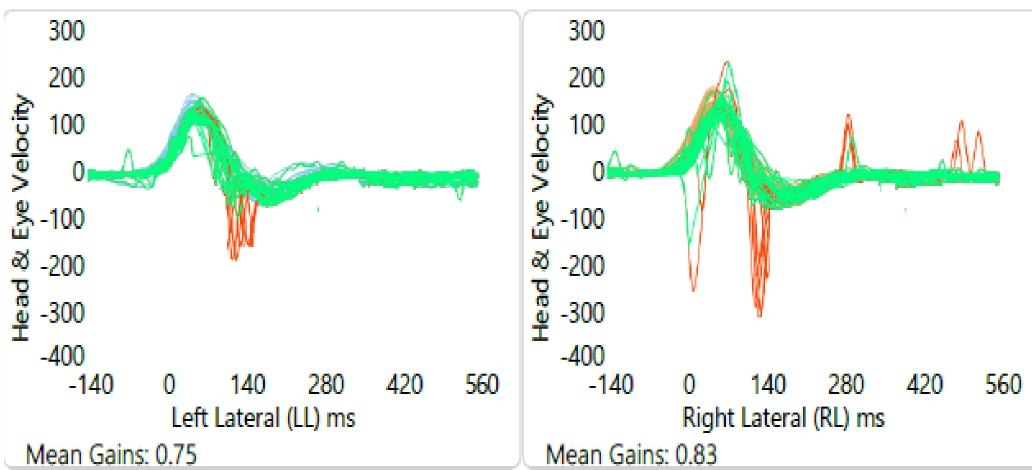

Figure: 4.10. *SHIMP test result of a participant having reduced anticompensatory saccade (abnormal) and normal mean vor gain in older adult group.*

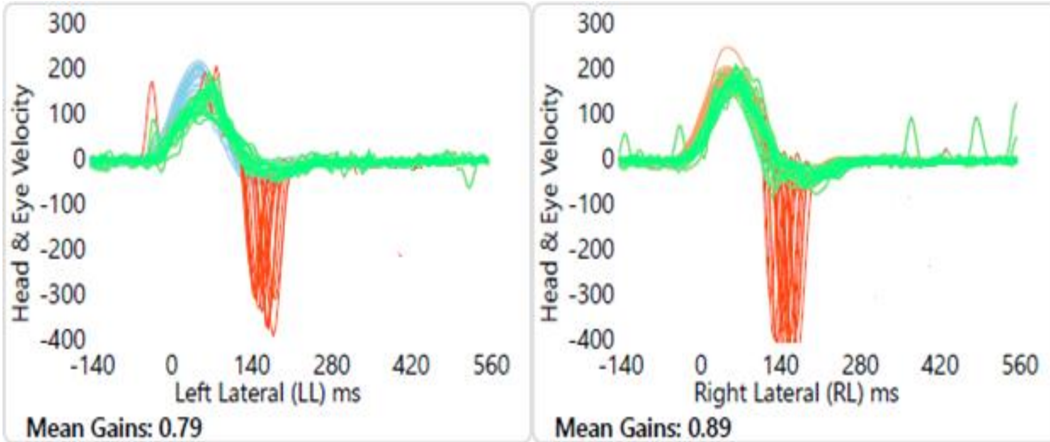

Figure: 4.11. *SHIMP test result of a participant having anticompensatory saccade (normal) and normal mean vor gain in older adult group.*

To summarize, the VOR gain obtained using Head impulse paradigm and Suppression head impulse paradigm was higher or better for younger adults compared to that of older adults. The younger adults group had a better or higher VOR gain value when compared to the gain values of 3 subgroups of the older adult group. This indicates that VOR gain starts to decline at the age of 40 years. All the participants of the study had normal HIMP VOR gain. SHIMP VOR gain was found to be within normative for all the participants of younger adult group. Whereas few participants of the older adult group had reduced or poorer SHIMP VOR gain and few had absent anticompensatory saccade. There was no association seen between the degree of hearing loss and VOR gain for both HIMP and SHIMP for both ears. That is VOR gain is independent of degree of hearing loss. The comparison of VOR gain values of both HIMP and SHIMP between male and female participants revealed no significant difference between groups. Hence, gender effect was not seen for both HIMP and SHIMP VOR gain.

Chapter-V

Discussion

5.1 Head Impulse Paradigm and Suppression Head Impulse Paradigm

The mean vestibulo-ocular reflex gain values obtained using Head Impulse Paradigm and Suppression Head Impulse paradigm were higher for younger adults than older adults, however the mean VOR gain for both the groups were within normal limits.

VOR gain has been reported to be reduced in older adults. Peterka et al., (1989) reported a decrement in VOR gain value due to the sinusoidal rotation with age, along with increased postural sway. Tian et al., (2001) also reported significantly lower VOR gain in older adults compared to the younger subjects. In each of the canal planes Agrawal et al., (2012) observed a significant deterioration in the functioning of semicircular canal along with the reduction in otolith functioning associated with aging. Mossman, et al., (2015) found that the horizontal vestibulo-ocular reflex velocity gain declined per decade as age is increased. And the VOR gain values were significantly different for younger adult and older adult group and the gain for younger adult being higher.

However, there are equivocal findings regarding the age at which the VOR gain starts to decline. Li et al., (2015) found that the relationship between VOR gain and age is non- linear. As age increases there was a considerable reduction in VOR gain especially in subjects older than 80 years. Matino Soler et al. (2015) reported significant reduced VOR gain in individuals above 70 years. Kim and Kim (2018), significant reduction in VOR gain of the horizontal canal above 70 years ad in the vertical canal above 80 years of age. Jay et al., (2019) reported a significant decline in VOR gain in the age groups 58–67 and 68–77 years. Agrawal et al., (2012) also reported not much change seen in the VOR gain up to the age of 50 years; however, the mean VOR gain is reduced in individuals beyond 60 years.

Few studies also reported no change in vestibulo-ocular reflex gain reduction as age increases. MacDougall et al., (2009) reported that vHIT had not referenced the variation of normal HVOR velocity gain concerning age. McGarvie et al., (2015) found that the horizontal canal gain and anterior canal gain did not vary largely with age; however, the average gain for the posterior canal decreased. Zou Shizhen et al. (2019) also reported that the gain of vHIT six semicircular canals, VOR has excellent age stability, and the age difference will not affect the vHIT result.

However, in the present study, we could find a significant significantly lower VOR gain in older adults using both the paradigms compared to the younger adults, but the VOR gain was within normal limits for older adults also. The decline in the number of receptor cells and the primary afferents of vestibular system could be the reason for reduction in VOR, gain values with age. In typical healthy young adults, there are a very substantial number of receptors in each of the canal, and this number declines with age (Engström et al., 1974), and this is an indicative of decline of the VOR with age. There occur structural changes from the vestibular hair cells up to vestibular nerve fibers. The reduction in nerve fibers occurs by around 2000 nerve fibers per decade and reaches up to 40% reduction by the age of 60 years (Bergstrom, 1972). The loss of nerve fibers starts to occur at 40 years of age (Park et al., 2001) hence with this loss of nerve fibers with increasing age there decline in carrying capacity of vestibular nerve which could have resulted in reduction in VOR gain with aging.

There were not many researches in the literature that studied the effect of age on VOR gain values obtained through SHIMP procedure. Hence there were no supporting studies having similar result of current study were obtained. Park and Cho (2019) reported that values of VOR gain did not vary considerably with age. The anticompensatory saccades in SHIMP and the values of VOR gain were constantly equal in each decade of life. The SHIMP normative gain value seems to be mostly not affected by aging. Furthermore studies have to be conducted in order to validate the result of the present study.

The findings of reduced VOR gain in older adults compared to the younger adults in the present study beginning at the age of 40 years is consistent with the suggestion that the vestibular dysfunction observed histopathologically may be clinically evident only in the older population. The outcomes of the present study are also reliable with the histopathologic reports presenting remarkable age-related decline in the number of vestibular sensory hair cells in human temporal bones (Rauch et al, 2001; Rosenhall, 1973; Walther & Westhofen, 2007) and also with the loss in the number of neurons in the human vestibular nucleus complex which is age-related (Lopez et al., 1997).

However, in the present study, the mean VOR gain was within normal limits for both groups. This must mean that the sensory vestibular regions will function comparatively fine with a decreased amount of both sensory cells and nerve fibers with significant products inside the epithelial cells which is of no use (Engström et al., 1974). The cerebellum controls the oculomotor response measured, and studies on the VOR has shown how essential is the cerebellum is for “restoring” the VOR in the face of “challenges,” such as magnified vision or may be age (Engström et al., 1974). The Cerebellar repair may be the reason for such relatively inconsequential effect of age.

5.2 Comparison of VOR gain between HIMP and SHIMP paradigm

The Head Impulse Paradigm gain obtained was slightly but significantly higher than the Suppression Head Impulse Paradigm gain in both older adult and younger adult group. And also right ear and left ear were significantly different in terms of HIMP and SHIMP VOR gain in both older adult group and younger adult group.

VOR gain obtained through HIMP has been reported to be slightly higher than SHIMP gain values. Many previously published studies have shown similar results that SHIMP VOR gain values were lower than HIMP gain values (MacDougall, 2016). Chen et al., (2018) found that there were small but significant differences between two sides regarding the gains in HIMP and SHIMP, and there was a small but significant difference between HIMP and SHIMP gains with SHIMP gain being lower. Devantier et al., (2018) reported that the SHIMP gain values were statistically lower than HIMP gain values. The lower VOR gain values obtained for SHIMP could be due to the saccade algorithm present in SHIMP paradigm.

Between the two groups, the right SHIMP VOR gain values had a statistically significant difference, but not for the left SHIMP gain values or the HIMP gain values. Rey-Martinez et al. (2018) found a small significant statistical difference between VOR gain values of both HIMP and SHIMP. The VOR gain values of HIMP and SHIMP were significantly lower when the impulses were initiated to the left side. Park and Cho

(2019) reported that SHIMP gain values were lower than HIMP gain values. The gain values obtained for the impulse towards right were higher than the gain values obtained for the impulse towards left. This difference may be attributable to physiologic difference in the eye movement (McGarvie et al, 2015) or to the fact that examiner was right handed (Bansal & Sinha, 2016). Another study reported that, VOR gain obtained between the corresponding left and right sides of the semicircular canal were not having any statistically significant difference (Zou Shizen, 2019). Roh et al., (2019) found that the VOR gain obtained by means of SHIMP protocol was lesser than using HIMP protocol and showed a statistically significant difference.

5.3 Association of VOR gain with degree of hearing loss

In the present study the results revealed no significant association between degree of hearing loss of right and left ear and HIMP and SHIMP VOR gain of right ear and left ear.

Result of the current study was contrary to some of the former findings present in the literature. Certain previous studies documented in literature have found a decrement of VOR gain function in subjects having sensorineural hearing loss which is of various origins. Sinha and Bansal (2017) studied individuals with congenital hearing loss and found a substantial reduction of VOR gain values in lateral and the right anterior-left posterior (RALP) plane. And it was inferred that different semicircular canals of both ears are affected in adult participants with congenital severe to profound hearing loss. Magliulo et al. (2015) administered vHIT in Usher syndrome who has established hearing loss and an abnormal vHIT was obtained in those individuals. And the study also revealed that 33.3% individual with Ushers syndrome had confirmed horizontal semicircular canal deficits. The results can be an indicative of semicircular canal's damage in individual with Ushers syndrome that had being correlated with degree of hearing loss. Lin et al., (2015) also reported an abnormal vHIT in 38.5% of individuals diagnosed with idiopathic sudden hearing loss when horizontal canal VOR gain was examined. Jutila et al., (2013) obtained a substantially reduced horizontal VOR gain values in children with profound hearing loss. Several pathologies had also shown smaller VOR gain values for horizontal canal which shows horizontal Semicircular canal dysfunction.

The difference in the findings of the present study and the earlier studies could be due to the fact that most of the previous studies have taken subjects with congenital sensorineural hearing loss whereas in the present study, a group of individuals with acquired sensorineural hearing loss was considered. Also, the previous studies had individuals with very severe to profound hearing loss, and in the present study, the participants had a milder degree of hearing loss.

5.4 Comparison of VOR gain between male and female

There was no significant difference in the HIMP and SHIMP VOR gain values when compared between male and female participants.

Zou Shizhen et al (2019) reported that the VOR gain obtained for six semicircular canals in normal population is not significantly different between different genders. There are studies were females had significantly higher mean VOR gains. Limited number of studies has reported no gender-related alterations in functioning of vestibular system.

Three-dimensional measurements of the human vestibular apparatus have shown that males are likely to have semicircular canals with wider diameter as well as larger surface areas of the utricular and saccular maculae (Sato et al., 1992). However, the functional significance of the gender variances in VOR found in this study is uncertain.

5.5 Presence/ absence of saccades in HIMP and SHIMP

All the participants of the study had no refixation saccades.

As age increases, refixation saccades with normal gain values have been documented to occur more frequently. The studies showed a lower gain values when refixation saccades occurred but they were still within the normative (Matiño-Soler et al., 2015; Perez et al., 2015). Aging is the only factor that can explain the presence of saccades as the subjects did not suffer from any vestibular disease. Aging can modify the vestibular system in a number of ways. Reduction in the amount of vestibular hair cells and certain age-related changes such as deformation of the cilia can affect the VOR. Loss in number of neurons within the vestibular system should also be considered. Such minor decline in VOR gain with increasing age can be a trigger for refixation saccades. A study was proposed that, in relation to young adults, saccade-generating mechanism in older adults may be impaired (Korsager et al., 2017). However, the presence of refixation saccades with normal gain values has also been reported in younger individuals. A study was done by Perez et al., (2015) suggested that the presence of refixation saccades may be a result of any vestibular pathology and may not be a matter of aging. Such damage can lead to saccades of low gain values and thus can weaken the VOR. Central compensation will occur with time which results in normal gain values. However, saccades will still occur, since the VOR is impaired (Korsager et al., 2016). However, the saccades will be present in unilateral vestibular pathologies and not in bilateral vestibular pathologies. Considering the group of participants in the present study, all of them had bilateral sensorineural hearing loss, the refixation saccades may not be present. Similarly, the anti-compensatory saccade will be present in bilateral vestibular pathology with reduced amplitude, however it will be absent in unilateral vestibular pathology.

Chapter-VI

Summary and conclusion

The health of elderly individuals who are the fastest-growing sector of our community is a significant concern worldwide. As age increases body starts to degenerate. This process of degeneration affects the entire body, including the vestibular system. Damage to the vestibular system due to aging often results in symptoms like vertigo and dizziness. The connection between the observed aging changes and the increased incidence of dizziness and falls in the elderly is has to be studied. In healthy young adults, there are a very significant number of receptors in each of the semicircular canal. Still, this number declines, and this deterioration in the number of vestibular hair cells happens as a result of aging. This may result in variances in vestibular system functioning, characterized by improved vestibulo- ocular reflex (VOR) gain alteration with advancing age.

Effective assessment of the function of vestibulo- ocular reflex can be done by administering specific tests. Caloric test is a clinically used tool for assessing horizontal semicircular canal however a novel video head impulse test with two of its variations such as Head Impulse Paradigm and Suppression Head Impulse Paradigm can be used to assess the semicircular canal in lateral planes for high frequency movements and thereby the function of vestibulo- ocular reflex. Thus, the present study aimed at studying the Vestibulo- ocular reflex gain using HIMP and SHIMP in older adults.

The objectives of the present study were:

1. To study the VOR gain values using Head Impulse Paradigm VS Suppression Head Impulse Paradigm in older adults
2. To study an association between the degree of hearing loss and VOR gain in younger and older adults.
3. To compare the VOR gain values between an older male and female participants.

To achieve the aim, the study included 60 participants with sensorineural hearing loss in the age range of 18 years - 70 years. The participants were divided into two groups. The group I consisted of 30 participants' in the age range between 40 years – 70 years (older adults) and group II consisted of 30 participants in the age range of 18 years – 40 years (younger adults). Each group consisted of 15 male and 15 female participants.

All the participants underwent routine audiological evaluation including detailed case history, audiometric evaluation, immittance audiometry to rule out middle ear pathology and Auditory Brainstem- Site of lesion testing to rule out retrocochlear pathology. The individuals having different degrees of sensorineural hearing loss were recruited for the study. None of the participants had history or presence of any vestibular complaints. Two variations of Video Head Impulse test such as Head Impulse Paradigm and Suppression Head Impulse Paradigm were administered in all participants and Vestibulo- ocular reflex gain values were calculated in lateral planes using both paradigm.

To analyze the data following statistics was done

- Descriptive statistics was done to find the mean and standard deviation of HIMP and SHIMP VOR gain in lateral planes for both older adult and younger adult group.
- Independent sample T test was done to compare the mean VOR gain values between younger and the older adults obtained using the HIMP and SHIMP paradigm.
- Multivariate analyses of variance (MANOVA) was done to compare significant differences in the mean values of HIMP and SHIMP VOR gain between the three subgroups of the older individuals and younger individuals for both right and left ear.
- Duncan's post hoc analyses was done to understand the significant difference between the different subgroups of older adults group and younger adults
- Paired sample T test was performed to compare between right ear and left ear in terms of HIMP and SHIMP VOR gain of older adult group and younger adult group.
- Chi- square test was done to see the association between HIMP, SHIMP VOR gain of right and left ear and degree of hearing loss of right and left ear of both the groups.
- Independent sample T test was performed to compare the HIMP and SHIMP VOR gain between male and female participants.

Results of the above statistical analyses revealed the following

- There was a significant difference in mean HIMP and SHIMP VOR gain values between older adult and younger adult group.

- A significant difference in VOR gain values between younger adults and three subgroups of older adults using HIMP and SHIMP technique.
- There existed a significant difference in right ear and left ear in terms of HIMP and SHIMP VOR gain in both groups.
- The HIMP and SHIMP VOR gain of right and left ear did not show any association with degree of hearing loss of right and left ear.
- There was no significant difference in HIMP and SHIMP gain values when compared between male and female participants.

Conclusions

Video Head Impulse test provides detailed information about semicircular canal function and its two variations such as Head Impulse Paradigm and Suppression Head Impulse Paradigm can be used to assess the functioning of vestibulo- ocular reflex. The findings of the present study suggest that VOR gain obtained using HIMP and SHIMP reduces as age increases. Both HIMP gain and SHIMP gain was better for younger adults compared to older adults. The finding of the present study implies that the VOR gain started to decline at 40 years of age for the older adults group. However, the VOR gain for both the groups remains within normal limits, suggesting some type of VOR gain compensation from the cerebellar system. To conclude, HIMP and SHIMP protocols are valuable tools to evaluate VOR during high-velocity head movements. Both the test protocols can be complementary methods for a comprehensive evaluation of vestibular function in individuals diagnosed with sensorineural hearing loss.

Implications of the study:

1. The present study helps us in assessing the VOR function of older adults.
2. The study provides us the knowledge regarding the changes seen in the functioning of the horizontal semicircular canal due to aging by using head impulse paradigm and suppression head impulse paradigm. Thus it can be used as a guideline to understand the change in VOR gain values obtained due to aging.

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