ARF Project

ASSESSMENT OF DIFFERENT VESTIBULAR PATHWAYS IN INDIVIDUALS WITH PERIPHERAL VESTIBULAR DISORDERS

Principal Investigator

Dr. Sujeet Kumar Sinha

Lecturer

Department of Audiology

Mysore.

Co-Investigator

Dr. Rajeshwari G

Professor

Department of Otorhinolaryngology

Personnel worked for the project

Kruthika Shankar

Project Officer

Introduction

Assessment of vestibular function includes battery of clinical, electrophysiological and questionnaire based tests. The audiological tests which are administered to assess the vestibular functions are detailed case history, puretone audiometry, immitance measurment, speech audiometry, otoacoustic emissions and auditory brainstem responses, electronystagmography (ENG) and vestibular evoked myogenic potentials (VEMPs). ENG is a diagnostic test to record the corneoretinal potentials through involuntary movements of the eye caused by a condition known as nystagmus. ENG mainly concerned with the ocular connections of the vestibular nuclei which are responsible for production of eye deviations constituting the slow phase of the vestibular nystagmus (Kirtane, 1985). Since the eye movements result in changes in the electrical field around the eyes and nystagmus and other related eye movements can be recorded using ENG which cannot be obtained by direct observation of the subject's eye.

The pathways which ENG assesses are horizontal semicircular canal, superior vestibular nerve, vestibular nucleus, contralateral abducens nucleus through medial longitudinal fasciculus (MLF), contralateral lateral rectus and through MLF to the ipsilateral oculomotor nucleus then to the medial rectus of the same side. This pathway contributes to the slow phase of the nystagmus. Certain neurons in the reticular formation of the brain stem are stimulated when this vestibular afferent activity reaches their threshold. These neurons will discharge impulses which counter the slow phase of the nystagmus and jerk them back to the original midline position. This is the fast phase of the nystagmus (Kirtane, 1985).

Compared to the auditory system, the vestibular system is more complex (Kirtane, 1985). Current electrophysiological evaluation of the vestibular system, such as ENG, does not assess all functional structures and pathways. ENG battery only assesses lateral semicircular canals and the superior vestibular nerve. By adding VEMP measurements, it is

possible to identify any dysfunction in the saccule and/or inferior vestibular nerve. VEMP are inhibitory electrical potentials which is generated in responses to a loud sound, and is originated in the saccule or its innervating structure and conducted by the inferior branch of the vestibular nerve. These inhibitory electrical potentials are picked up by electrodes placed on the sternocleidomastoid muscle (SCM). Pathway involved in the VEMP includes the saccular macula, inferior vestibular nerve, the medial vestibular nucleus, the medial vestibulospinal tract, the sinal accessory nuclei and the motor neurons of ipsilateral SCM muscle (Halmagyi & Curthoys, 1999). These VEMP responses are called as cervical vestibular evoked myogenic potentials (cVEMP).

There is another variant of vestibular evoked myogenic potentials which are called as the ocular vestibular evoked myogenic potential (oVEMP). oVEMP responses (negative peak at 10 ms and a positive peak around 15 ms) are vestibular in origin and most likely originating from the otolith-ocular pathway (Chihara, Iwasaki, Ushio & Murofushi, 2009). The ocular vestibular evoked myogenic potentials are myogenic in nature and are thought to arise from the otolith-ocular reflex (Chihara et al., 2009; Rosengren, Todd & Colebatch, 2005; Todd, Rosengren, Aw, & Colebatch, 2007; Welgampola, Migliaccio, Myrie, Minor, & Carey, 2009).

The neuronal pathway for oVEMPs includes utricle, superior branch of the vestibular nerve, vestibular nucleus, from the vestibular nucleus through a contralateral pathway tomedial longitudinal fasciculus and from medial longitudinal fasciculus to the inferior oblique muscle (Rosengren, Welgampola, & Colebatch, 2010). cVEMPs and oVEMPs responses can be evoked by the air conduction click or tone burst, bone conduction click or tone burst, tapping on the skull, and galvanic stimulation.

cVEMPs responses mainly assess the function of saccule and inferior vestibular nerve. cVEMPs have also been utilized to diagnose the different vestibular disorders such as

vestibular schwannoma, Meniere's disease, vestibular neuritis and BPPV (Akkuzu, Akkuzu & Ozluoglu 2006; Boleas-Aguirre, Sanchez-Ferrandiz, Artieda, & Perez, 2007; Hong, Yeo, Kim & Cha, 2008; Murofushi, Halmagvi, Yavor & Colebatch, 1996; Murofushi, Shimizu, Takegoshi, & Cheng, 2001).

oVEMPs responses mainly assess the function of otolith organs and superior vestibular nerve. oVEMPs have also been found to very useful in diagnosis of different vestibular disorders such as Meniere's disease, superior canal dehiscence syndrome, BPPV (Chiarovano, Zamith, Vidal & Waele, 2011; Huang, Wang & Young, 2012; Jacobson, et al., 2011; Murofushi, Nakahara, Yoshimura & Tsuda, 2011). Combination of ENG, cVEMPs and oVEMPs may provide valuable information regarding the pathways involved in different vestibular dysfunction.

Equivocal studies are available in the literature regarding the diagnostic significance of ENG in patients with vestibular dysfunction (Coats, 1970; Goodhill, 1979; Pflatz, 1984; Ojala, Vaheri & Juntenen, 1989; Colledge, Barr-Hamilton, Lewis, Sellar & Wilson, 1997; Shi, Yu, Niu & Lu, 1997; Bhansali & Honrubia, 1999; Bakr & Saleh, 2000). The equivocal findings might be due to the fact that, earlier tests for assessing the integrity of sacculo-collic pathway and otolith ocular reflex pathway were not available. Utricle and saccule are important structures which help in translational movements. Problems in any of the structure can lead to a dysbalance in individuals. Thus, there is need to study the integrity of different vestibular pathways (semicircular canal ocular reflex pathway, vestibulo-collic reflex pathway and otolith ocular reflex pathway) using ENG, cVEMP and oVEMP in differential diagnosis of vestibular dysfunction.

Equivocal findings also have been reported in association of ENG, cVEMP and oVEMP responses in individuals with various vestibular dysfunctions (Chiarovano, Zamith, Vidal & Waele, 2011; Jacobson et al. 2011; Murofushi, Nakahara, Yoshimura & Tsuda,

2011). Hence there is a need to study ENG, cVEMP and oVEMP in individuals with various peripheral vestibular dysfunction.

Method

Participants

Two groups of participants were enrolled in the present study, clinical group and the control group. Clinical group was further subdivided in to three subgroups of participants. First clinical subgroup consisted of 29 participants (18 males & 11 females) with definite Meniere's disease in the age range of 18 to 55 years (Mean age = 39.25 years). Out of 29 participants, 25 participants had unilateral Meniere's disease and 4 had bilateral Meniere's disease. The diagnosis of definite Meniere's disease was based on symptoms exhibited by the participants and an otolaryngologist who diagnosed the case based on guidelines proposed by the American Academy of Otolaryngology Head and Neck Surgery (1995). The details of the participants with Meniere's disease are given in Table-1

Table-1

Demographic details of the participants with Meniere's disease.

Sl.No	**Age (years)**	**Sex**	**Ear**	**Air conduction thresholds (dBHL)**						**ABR**	**Immittance**
				250Hz	500Hz	1kHz	2kHz	4kHz	8kHz		
1	34	M	Rt	15	15	20	15	15	20	N	"A", PR
			Lt	30	35	40	45	45	55	N	"A" PR
2	45	M	Rt	10	15	15	15	20	20	N	"A" PR
			Lt	20	25	25	25	30	35	N	"A" PR
3	36	F	Rt	15	20	20	20	25	25	N	"A" PR
			Lt	25	30	30	30	35	40	N	"A" PR
4	30	M	Rt	30	30	35	35	40	40	N	"A" PR

			Lt	10	10	15	15	20	20	N	“A” PR
5	46	M	Rt	20	25	30	35	40	45	N	“A” PR
			Lt	25	35	35	40	45	45	N	“A” PR
6	31	F	Rt	20	25	25	30	35	35	N	“A” PR
			Lt	40	45	45	50	55	55	N	“A” PR
7	32	M	Rt	25	30	35	35	40	45	N	“A” PR
			Lt	35	40	40	45	40	50	N	“A” PR
8	28	M	Rt	30	40	40	45	45	50	N	“A” PR
			Lt	40	45	45	55	55	50	N	“A” PR
9	42	F	Rt	20	25	30	35	35	45	N	“A” PR
			Lt	40	45	50	50	55	60	N	“A” PR
10	40	M	Rt	10	15	20	10	15	20	N	“A” PR
			Lt	45	50	55	55	60	65	N	“A” PR
11	41	M	Rt	15	15	20	10	15	25	N	“A” PR
			Lt	35	45	40	45	50	55	N	“A” PR
12	35	M	Rt	10	5	15	10	15	20	N	“A” PR
			Lt	25	35	30	35	40	45	N	“A” PR
13	37	M	Rt	10	15	20	10	15	20	N	“A” PR
			Lt	35	45	45	40	55	50	N	“A” PR
14	49	F	Rt	25	35	30	40	45	45	N	“A” PR
			Lt	15	10	15	20	15	25	N	“A” PR
15	34	M	Rt	15	15	20	10	15	15	N	“A” PR
			Lt	30	35	40	45	40	50	N	“A” PR
16	26	F	Rt	20	15	10	15	20	25	N	“A” PR

			Lt	25	35	40	45	55	55	N	“A” PR
17	29	F	Rt	25	35	30	35	40	45	N	“A” PR
			Lt	30	35	25	30	35	40	N	“A” PR
18	55	M	Rt	10	15	10	15	15	15	N	“A” PR
			Lt	20	25	20	30	25	30	N	“A” PR
19	39	M	Rt	30	35	30	35	40	40	N	“A” PR
			Lt	10	15	10	15	20	15	N	“A” PR
20	36	F	Rt	15	10	15	20	15	25	N	“A” PR
			Lt	35	45	40	45	50	55	N	“A” PR
21	43	M	Rt	15	10	15	20	25	30	N	“A” PR
			Lt	35	40	45	55	50	55	N	“A” PR
22	31	M	Rt	10	15	15	10	15	20	N	“A” PR
			Lt	35	35	45	40	30	35	N	“A” PR
23	18	M	Rt	40	55	55	50	55	60	N	“A” PR
			Lt	10	15	20	10	15	20	N	“A” PR
24	41	M	Rt	30	35	40	35	45	45	N	“A” PR
			Lt	15	10	15	20	25	15	N	“A” PR
25	33	M	Rt	30	35	40	45	30	40	N	“A” PR
			Lt	10	10	20	15	25	25	N	“A” PR

N=Normal, PR= Present, A/As: type of tympanogram

Second clinical subgroup consisted participants with vestibular neuritis. Total 6 participants were enrolled for the study (age range-22 to 40 years, 1 female, 5 males). All of them were diagnosed with vestibular neuritis based on history of upper respiratory tract infection and vestibular sign and symptoms in the absence of the any hearing loss or ear

related symptoms. The diagnosis of vestibular neuritis was confirmed by the otorhinolaryngologist. The side of involvement i.e whether the right ear is involved or left ear was involved decided based on absence of caloric test on the right or the left side. The details of the participants with vestibular neuritisare given in table-2

Table 2

Participants with vestibular neuritis with results of tests on audiological test battery

Sl.No	Age (years)	Sex	Ear	Air conduction thresholds (dBHL) 250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	ABR	Immittance
1	28	M	**Rt***	**15**	**15**	**20**	**15**	**15**	**20**	**N**	**"As", PR**
			Lt	10	15	20	15	10	15	N	"A", PR
2	32	F	**Rt***	**10**	**15**	**15**	**15**	**20**	**20**	**N**	**"A", PR**
			Lt	5	10	15	10	15	15	N	"As", PR
3	38	M	Rt	15	10	15	20	15	10	N	"A", PR
			Lt*	**10**	**15**	**15**	**20**	**15**	**20**	**N**	**"A", PR**
4	30	M	**Rt***	**15**	**10**	**15**	**15**	**20**	**15**	**N**	**"As", PR**
			Lt	10	15	15	20	15	20	N	"A", PR
5	40	M	**Rt***	**10**	**15**	**15**	**20**	**20**	**25**	**N**	**"A", PR**
			Lt	10	15	15	10	20	15	N	"A", PR
6	22	M	Rt	10	10	15	15	15	20	N	"A", PR
			Lt*	**5**	**15**	**10**	**15**	**25**	**20**	**N**	**"A", PR**

N=normal response, PR=present, "A"/As= "A" or As type tympanogram *Affected ears

Third clinical subgroup consisted of participants with benign paroxysmal positional vertigo (BPPV). Total 25 participants were enrolled for the study (age range 31-58 years, 12 males, and 13 females). All the participants had positional vertigo and diagnosis of BPPV was confirmed by the otorhinolaryngologist. Also the side of the involvement was confirmed based on the Dix Hallpike test results i.e the head position (righ/left) on which the symptoms worsened was considered to be the side involved in BPPV.

The details of the participants enrolled for the study are given in table-3

Table 3

BPPV Subject details along with results on the audiological test battery

Sl. No	Age (years)	Sex	Ear	Air conduction thresholds (dBHL)						ABR	Immittance
				250Hz	500Hz	1kHz	2kHz	4kHz	8kHz		
1	25	F	Rt	15	15	20	15	15	20	N	"A",PR
			Lt	10	15	20	15	10	15	N	"A",PR
2	45	M	Rt	10	15	15	15	20	20	N	"A",PR
			Lt	5	10	15	10	15	15	N	"A",PR
3	36	F	Rt	15	10	15	20	15	10	N	"A",PR
			Lt	10	15	15	20	15	20	N	"A",PR
4	47	F	Rt	15	10	15	15	20	15	N	"A",PR
			Lt	10	15	15	20	15	20	N	"A",PR
5	56	M	Rt	10	15	15	20	20	25	N	"A",PR
			Lt	10	15	15	20	20	25	N	"A",PR
6	58	M	Rt	10	10	15	15	25	20	N	"A",PR
			Lt	5	15	10	15	25	20	N	"A",PR
7	32	M	Rt	15	10	15	15	20	15	N	"A",PR

			Lt	10	15	15	10	15	15	N	“A”,PR
8	48	M	Rt	10	10	15	20	15	25	N	“A”,PR
			Lt	5	10	15	15	10	15	N	“A”,PR
9	40	F	Rt	10	15	15	10	20	15	N	“A”,PR
			Lt	15	10	15	15	20	25	N	“A”,PR
10	32	M	Rt	10	15	20	10	15	20	N	“A”,PR
			Lt	10	15	15	10	20	15	N	“A”,PR
11	41	M	Rt	15	15	20	10	15	25	N	“A”,PR
			Lt	10	15	15	10	15	15	N	“A”,PR
12	35	M	Rt	10	5	15	10	15	20	N	“A”,PR
			Lt	5	10	15	15	10	15	N	“A”,PR
13	31	M	Rt	10	15	20	10	15	20	N	“A”,PR
			Lt	10	15	15	10	20	15	N	“A”,PR
14	35	F	Rt	5	10	15	10	15	15	N	“A”,PR
			Lt	15	10	15	20	15	25	N	“A”,PR
15	36	M	Rt	15	15	20	10	15	15	N	“A”,PR
			Lt	15	10	15	15	20	25	N	“A”,PR
16	29	F	Rt	20	15	10	15	20	25	N	“A”,PR
			Lt	5	10	15	15	10	15	N	“A”,PR
17	31	F	Rt	10	15	15	10	20	15	N	“A”,PR
			Lt	5	10	15	10	15	15	N	“A”,PR
18	39	M	Rt	10	15	10	15	15	15	N	“A”,PR
			Lt	10	15	20	10	15	20	N	“A”,PR
19	36	M	Rt	10	15	15	15	20	20	N	“A”,PR

			Lt	10	15	10	15	20	15	N	“A”,PR
20	31	F	Rt	15	10	15	20	15	25	N	“A”,PR
			Lt	15	10	15	15	20	15	N	“A”,PR
21	41	M	Rt	15	10	15	20	25	30	N	“A”,PR
			Lt	10	15	15	10	15	15	N	“A”,PR
22	29	M	Rt	10	15	15	10	15	20	N	“A”,PR
			Lt	10	10	15	15	15	20	N	“A”,PR
23	52	M	Rt	5	15	10	35	25	30	N	“A”,PR
			Lt	10	15	20	20	25	30	N	“A”,PR
24	40	M	Rt	15	10	15	20	15	15	N	“A”,PR
			Lt	15	10	15	20	25	15	N	“A”,PR
25	58	M	Rt	15	15	20	20	35	40	N	“A”,PR
			Lt	10	20	20	25	25	45	N	“A”,PR

*N=normal response, PR=present, “A”= “A” type tympanogram

Control group consisted of 15 participants (30 ears) (8 males & 9 females, age range 18 years to 58 years). All the participants in the control group had normal hearing sensitivity with no middle ear pathology. Additionally these participants did not have any vestibular symptoms and any history or presence of any other otological disorders.

Instrumentation and test environment

A calibrated two channel GSI-61diagnostic audiometer with TDH – 39 headphones, and B-71 bone vibrator was used for pure tone audiometry. Calibrated GSI TYMPSTAR immitance meter was used for tympanometry and relexometry. Intelligent Hearing systems (IHS version 4.3.02) was used for recording auditory brainstem responses and air conducted click evoked cervical VEMP. Biologic navigator Pro EP instrument with biologic insert was used for ocular VEMP recording. RMS Medicare ENG instrument was utilised for recording

caloric responses. All the audiological tests were conducted in the acoustically treated rooms and noise levels during the testing were within permissible limits (ANSI, 1991).

Procedure

A detailed case history was taken for each participant prior to testing. Puretone Air conduction thresholds were obtained from 250Hz to 8000Hz and bone conduction thresholds were determined from 250Hz to 4000Hz at octave frequencies for all the participants. Immittance audiometry was carried out in both ears using a probe tone frequency of 226 Hz. Tympanomery was done initially and then ipsilateral and contralateral acoustic reflex threshold was measured for 500, 1000, 2000, and 4000 Hz stimuli. UCL was obtained in both ears for air conducted speech stimuli using ascending method. Followed by this, the auditory brainstem responses (ABR) were recorded for both the ears to rule out any retro cochlear pathology. Two channel ABR recording was done for 100µsec click stimuli at 90 dBnHL with the rarefaction polarity. The repetition rate used was 11.1/sec and 90.1/sec. Absolute and the interpeak latency of ABR was calculated to rule out any retrocochlear pathology. All the responses were filtered between 100 Hz to 3000Hz. The above mentioned test was done for the selection of the participants.

Vestibular evoked myogenic potentials

Cervical Vestibular evoked myogenic potentials (cVEMP)

The participants were instructed to sit straight and turn their head to the opposite side of the ear in which stimulus was presented, so as to activate ipsilateral sternocleidomastoid (SCM) muscle, as it gives reliable and greater amplitude. cVEMP was recorded using 500 Hz tone burst presented at a rate of 5.1/sec using rarefaction polarity. 500 Hz tone burst stimuli was used as the 500 Hz tone burst stimulus gives better amplitude of the cVEMP (Kumar, Sinha, Bharti & Barman, 2011). The stimuli were presented to the test ear at an intensity of 95 dBnHL using ER – 3A insert ear phones. The responses were recorded for 70 msec post

stimulus period along with the 10 msec pre-stimulus period. The recorded responses were then amplified (X 5000) and band pass filtered between 30 to 1500 Hz. The responses were averaged totally for 200 stimuli. Visual feedback system available in the instrument was utilized during the recording in order to ensure that the subjects monitored the tonic EMG activity of the SCM and maintained it between 100% to 200 %(50μv to 100μv) to obtain optimum responses. A visual feedback device was given to the participants so that the participants can look at the feedback device and can maintain the tonicity of the muscle.

Ocular Vestibular evoked myogenic potentials

oVEMP was recorded for all the participants with upper gaze direction. Participants were instructed to maintain the same upper gaze throughout the test run. 500 Hz tone burst was presented at a rate of 5.1/sec using rarefaction polarity. The stimuli were presented monaurally at an intensity of 95 dBnHL to the contralateral ear using ER – 3A insert ear phones. 200 stimuli were used for response averaging. The response was analysed for 60 msec post stimulus period. A pre-stimulus period of 10 msec was utilised to record background electrical activity. The recorded electrical responses were amplified (X 5000) and band pass filtered between 1 Hz to 1000 Hz. oVEMP responses were recorded twice in each ear to ensure replicability of the responses.

Caloric testing

Prior to the testing, ENG equipment was calibrated for each participant using a calibration light bar. All the participants were asked to stop taking anti-vertigo medications 48 hours before the testing. Participants were also asked not to consume alcohol 48 hours before the testing. In caloric test, open loop water irrigation was used to stimulate the horizontal semicircular canal. The temperature selected for warm stimulation was 44^{o} C and temperature for cold stimulation was 30^{o} C. 200ml of fluid was irrigated over a period of 30 secs. The order of irrigation used were, right 44^{o} C, left 44^{o} C, right 30^{o} C, and left 30^{o} C.

Recording was done for 3 minutes including the period for which the fluid was irrigated. A rest period of 7 minutes was given between two successive irrigations. The alertness of participants was maintained throughout the test by giving simple arithmetic problems.

The cumulative frequency was chosen as the parameter to be represented on the butterfly chart. The response waves obtained in the 4 conditions were analysed and the cumulative frequency was calculated. In order to calculate it, the recordings were divided into 10sec intervals. The 3 adjacent intervals having the most number of nystagmus beats, as determined by manual calculations in each 10sec interval, were considered. Thus, the cumulative frequency represented the total number of beats present over a 30sec period. The cumulative frequency response was plotted on the Claussen butterfly chart as reported earlier (Claussen & Von Schlachta, 1972; Kirtane, Merchant, & Medikeri, 1986; Sinha, Barman, Singh, Rajeshwari & Sharanya, 2013).

Results

Test Findings in control group

Cervical - vestibular evoked myogenic potentials (cVEMP)

cVEMP responses could be recorded in all the participants in the control group. In cVEMP, the latency of P1 and N1 peaks, amplitude of P1-N1 complex and amplitude asymmetry (between the two ears) were analyzed. Descriptive statistics was done to find out mean and standard deviation for P1 and N1 latencies, amplitude of P1-N1 complex, and inter-ear amplitude asymmetry for P1-N1 complex. The descriptive results of latency, amplitude of p1-n1 complex and inter-ear amplitude asymmetry for P1-N1 complex for the control group is shown in table 4.

Table- 4

Mean and standard deviation (SD) values of latency and amplitude measures of cVEMPs in control group

Parameters	Mean	SD
P1 latency (msec)	15.10	1.24
N1 latency (msec)	22.45	2.05
Amplitude of P1-N1 complex (µv)	40.39	12.66

Ocular vestibular evoked myogenic potentials

Latency of n1, p1 and n2, peak to peak amplitude of n1-p1 and p1-n2 complex, and inter-ear amplitude asymmetry were analyzed in oVEMP. The oVEMPs could be recorded in all the participants of the control group. Descriptive statistics was done to find out the mean and standard deviation of latency and amplitude parameters of oVEMP. Mean and standard deviation of latency of n1, p1 and n2 and amplitude measures are shown in table 5

Table- 5

Mean and standard deviation (S.D) values of latency and amplitude measures of oVEMPs in control group

Parameters	**Mean**	**Standard deviation**
n1 latency (msec)	11.37	0.96
p1 latency (msec)	16.49	0.90
Amplitude of n1-p1 complex (µv)	9.02	6.31
Amplitude of p1-n2 complex (µv)	8.16	5.62

Caloric test

Bithermal caloric test was recorded from all the subjects in the control group. The culmination frequency was calculated for all the participants in the control group. In control group, the range of culmination frequency of nystagmus in response to different caloric stimulation is shown in table 6.

Table – 6

Range of culmination frequency/30 seconds for all four caloric stimulation in control group.

Caloric stimulation	**Range of culmination frequency per 30 seconds**
Right warm	22 – 59
Left warm	20 – 70
Right cold	21 – 51
Left cold	22 – 64

Claussen's butterfly chart was made from the culmination frequency obtained from the participants in the control group. Figure 1 shows a butterfly chart obtained from one of the participants in the control group.

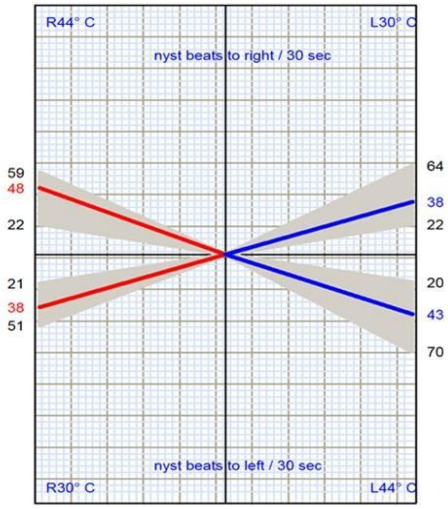

Figure 1. Results of caloric test for one participant in control group as shown in butterfly chart.

Vestibular Findings in Individuals with Meniere's disease

A total of 29 subjects in the Meniere's disease group were evaluated using the vestibular evoked myogenic potentials (cVEMP and oVEMP) and caloric test. Out of 29 subjects 4 had bilateral pathology whereas 25 had unilateral pathology.

Cervical Vestibular evoked myogenic potentials (cVEMP) results

cVEMP recordings showed that, out of 33 ears (29 participants) with Meniere's disease, 29 ears had absence of cVEMP responses (87.87%), and remaining four participants the cVEMP recordings were present. Descriptive statistics was done to find out the mean and standard deviations for P1 latency, N1 latency and P1-N1 amplitude for the four subjects in whom the responses were present. The mean latency of P1 peak was 15.16 msec (SD=1.23 msec), the mean latency of N1 peak was 22.68 msec (SD=2.09 msec) and mean amplitude of P1-N1 peak complex was 40.30 µv (SD=12.90). We did not calculate the inter-ear amplitude asymmetry ratio, as in most of the individuals the cVEMP responses were absent. A Kruskal Wallis test was done to find out the significant difference between normal hearing participants and participants with Meniere's disease. Kruskal Wallis test revealed no significant difference for P1 latency between the two groups ($p>0.05$), P1-N1 amplitude complex between the two groups ($p>0.050$, however Kruskal Wallis test showed s significant difference for N1 peak latency between the two groups ($p<0.05$). cVEMP recording of one participant with Meniere's disease is shown in figure 2

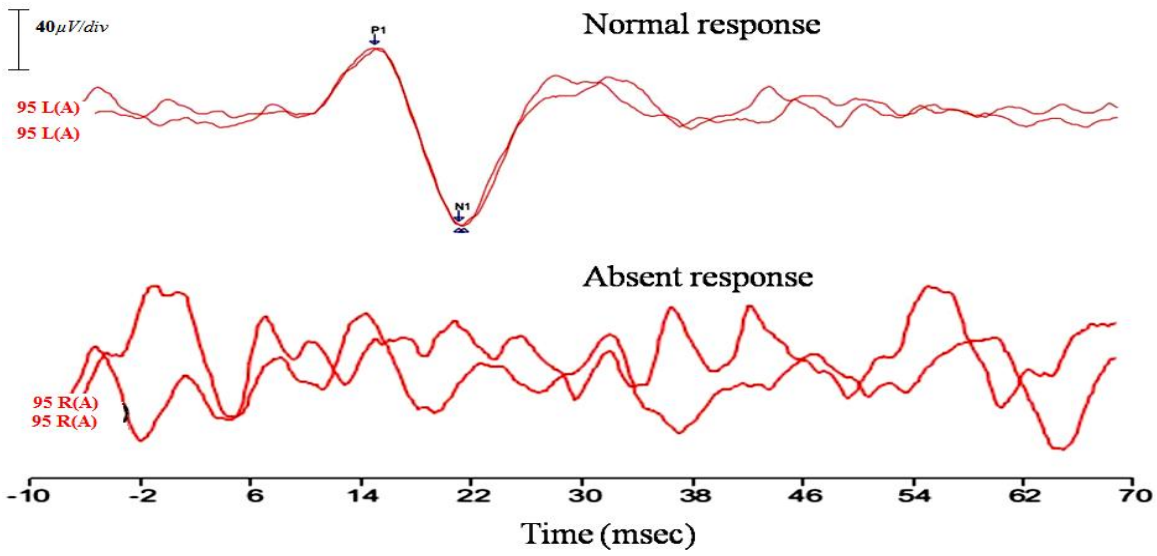

Figure – 2. Presence of cVEMP in left ear and absence of cVEMP in right ear for one of the Participant diagnosed with right Meniere's disease.

Ocular Vestibular evoked myogenic potentials

In oVEMP recordings, out of 33 ears, 23 ears showed absent responses (69.69%) and 10 ears showed present oVEMP response (30.30%). Descriptive statistics was done to find out the mean and standard deviations for the oVEMPs parameters for the Meniere's disease participants for whom the responses were present.

The mean latency for n1 peak was 11.50 msec (SD= 0.93), mean latency for p1 peak was 16.57 msec (SD=0.90), mean latency of N2 peak was 21.71 msec (SD=1.67), the mean amplitude of n1-p1 peak complex was 7.86 μv (SD=5.90), whereas the mean amplitude of p1-n2 complex was 7.09 μv (SD= 5.26). Kruskal wallis test was done to determine the significant difference between normal hearing individuals and individuals with Meniere's disease. Kruskal wallis test did not reveal any significant difference for n1 latency, p1 latency and n2 latency between normal and Meniere's disease individuals ($p>0.05$), whereas Kruskal wallis test revealed a significant difference for n1-p1 amplitude complex ($p<0.05$) and also for p1-n2 amplitude complex ($p<0.05$). oVEMP recording of one participant with right Meniere's disease is shown in figure 3

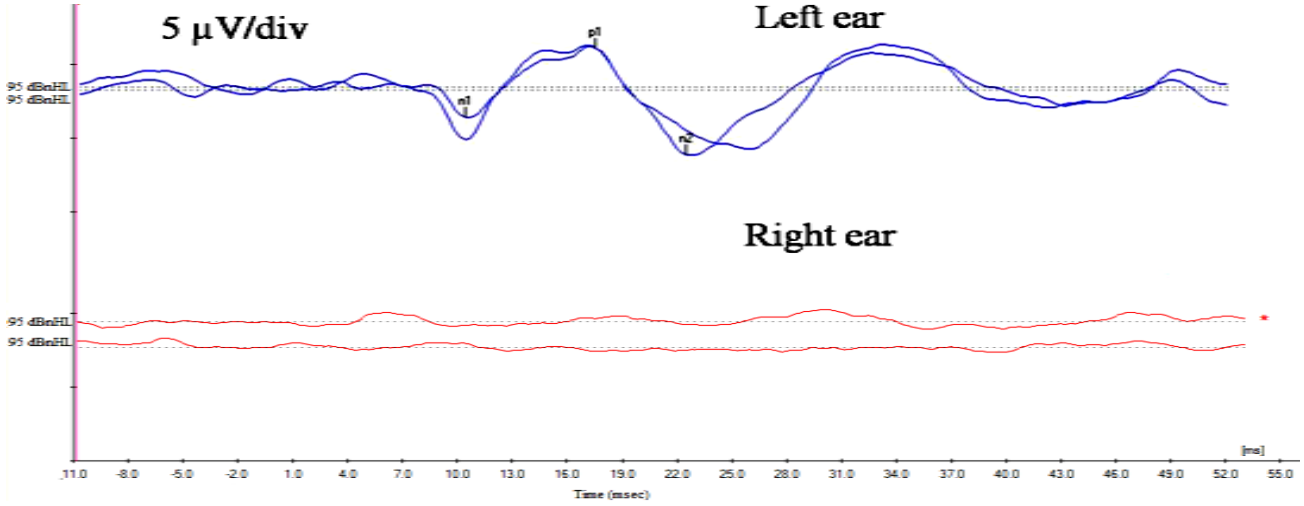

Figure. 3. Presence of Ovemp response in left ear and absence of oVEMP in right ear from one of the participants diagnosed with Meniere's disease.

Caloric test findings

In caloric test, out of 33 ears with Meniere's disease, hypo activity was noted in 27 affected ear (81.81%), 5 ears showed hyper activity (15.15%) and one ear showed normal response (3.03%) to caloric stimulation. Figure 4 shows butterfly charts of a hypoactive, hyperactive and a normal response.

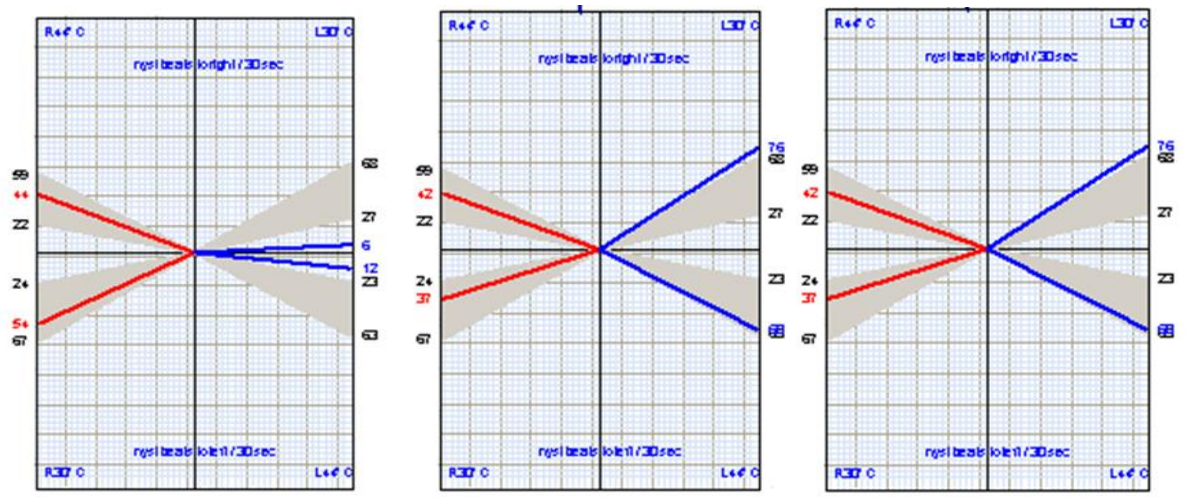

Figure-4. Butterfly chart showing a hypoactive, a hyperactive and a normal response in individuals with Meniere's disease

Association of Caloric test, cVEMP and oVEMP results in affected ears of subjects with Meniere's disease

Out of 33 ears, 22 ears showed (66.67%) abnormal results in both caloric test and oVEMP. None of the ear showed normal findings in both the tests. In 20 ears (60.60%) with Meniere's disease, both oVEMP and cVEMP were absent. One ear (3.03%) showed normal response in both the tests. 28 ears showed (84.84%) abnormal results in both caloric test and oVEMP. None of the ear showed normal findings in both the tests.

To find out any significant association between the Calorics tests and cVEMP, Caloric tests and oVEMP, oVEMP and cVEMP responses, a Chi square test was done. Chi-square test revealed no significant association between any of the two tests. Results of chi-square test are shown in table 7.

Table 7

Association of caloric test, oVEMP and cVEMP in individuals with Meniere's disease

Test		**oVEMP**			**cVEMP**		
		Normal	**Absent**	**Total**	**Normal**	**Absent**	**Total**
Caloric test	Normal	0	1	1	0	4	4
	Absent	10	22	32	1	28	29
	Total	10	23	33	1	32	33
	p value*	0.697			0.879		
cVEMP	Normal	1	3	4			
	Absent	9	20	29			
	Total	10	23	33			
	p value*	0.649					

*Chi-square test

It is evident from the table 4 that none of the pair of vestibular tests show a significant association between them ($p>0.01$).

Vestibular findings in contralateral ears of individuals with Meniere's disease

The intact ears (n=25) of individuals with Meniere's disease, all ears showed normal caloric results. Out of 25 ears, 16 ears had absent responses for cVEMP and 6 ears had absence of responses in oVEMP. Caloric test indicated normal responses in all the contralateral ears considered for the current study. Descriptive statistics was done to find out the mean and standard deviations for the latency and amplitude parameters of the cVEMP and oVEMP and are given in table-8

Table-8

Mean and Standard deviation (SD) for the latency and amplitude parameters of the cVEMP and oVEMP in the contralateral ear

Potentials	Parameters	Mean	SD
cVEMP	P1 Latency (msec)	14.89	1.09
	N1 Latency (msec)	22.14	2.29
	P1-N1 amplitude complex(µv)	39.66	13.01
oVEMP	n1 latency	12.04	0.75
	p1 latency	16.39	0.86
	n1-p1 amplitude complex (µv)	5.21	2.39
	p1-n2 amplitude complex (µv)	4.95	2.94

Kruskal Wallis test was done to find out the significant difference between the cVEMP and oVEMP of Meniere's disease and normal hearing individuals. Kruskal Wallis test results revealed a significant difference for n1 latency of oVEMP ($p<0.05$) and p1n2 amplitude of the oVEMP between normal and Meniere's disease individuals. For rest of the

cVEMP and oVEMP parameters, Kruskal Wallis test did not reveal any significant difference between the two groups.

Association of Caloric test, cVEMP and oVEMP results in contralateral ears of subjects with Meniere's disease

To find out any association between the cVEMP, oVEMP and Caloric test in contralateral ears of Meniere's disease a Chi-square test was administered. Chi square test could be administered only between cVEMP and oVEMP and could not be done between caloric test and cVEMP or oVEMP as the responses for caloric test was present normally in all the subject. Results of the Chi-square test are given in table 9.

Table -9

Association of cVEMP and oVEMP results in contralateral ears of individuals with Meniere's disease

Test		**cVEMP**		
		Absent	**Present**	**Total**
oVEMP	Absent	5	1	6
	Present	13	6	19
	Total	18	7	25
	p value*	0.50		

**Chi-square test*

It can be seen in Table-6 that both cVEMP and oVEMP were absent in 5 of the ears, cVEMP was absent and oVEMP was present in 13 of the ears, cVEMP was present and oVEMP was absent in 1 ear, whereas both cVEMP and oVEMP was present in 6 individuals with Meniere's disease. Chi-square test failed to reveal any significant association between cVEMP and oVEMP results in unaffected ears of individuals with Meniere's disease.

Vestibular test findings in Vestibular neuritis

Total 6 subjects with unilateral vestibular neuritis participated in the present study. Out of 6 participants vestibular neuritis was diagnosed in 4 right ears and 2 left ears.

Cervical vestibular evoked myogenic potentials-cVEMP findings

Out of 6 participants with vestibular neuritis, 5 participants had presence of response on cVEMP (83.33%), whereas one participant had absence of cVEMP response (16.67%). Descriptive statistics was done to find out the mean and standard deviation of latency and amplitude parameters of cVEMP. The mean and the standard deviation of the cVEMP parameters for subjects with vestibular neuritis are given in Table 10

Table 10

Mean and standard deviations (SD) for cVEMP in individuals with vestibular neuritis

Parameters	Mean (N=5)	Standard deviation
p13 latency (msec)	14.64	0.66
n23 latency (msec)	22.10	1.78
Amplitude of p13-n23 complex(µv)	31.89	5.09

Kruskal- Wallis test was carried out in order to find if the number of subjects with normal responses on cVEMP had responses similar to that of control group findings on cVEMP. Kruskal Wallis test revealed no significant difference in latency for N1 peak ($p>0.05$), no significant difference in latency between individuals with vestibular neuritis and normal hearing for P1 latency ($p>0.05$). Kruskal Wallis test also did not reveal a significant difference for P1-N1 amplitude complex between normal hearing individuals and individuals with vestibular neuritis ($p>0.05$).

oVEMP test findings

Out of 6 individuals with vestibular neuritis, 4 individuals had absent response i.e., 66.67% of the individuals with vestibular neuritis had absence of oVEMP. 2 subjects (33.33%) had present oVEMP responses. Mean and standard deviation of the latency and amplitude parameters were determined for n1, p1 and n2 latency, n1-p1 amplitude and p1-n2 amplitude. Table 11 indicates the results of descriptive statistics in individuals with vestibular neuritis

Table 11

Results of descriptive statistics on oVEMP test in individuals with vestibular neuritis

Parameters	**Mean (N=2)**	**Standard Deviation**
N1 latency	11.14	0.62
P1 latency	17.26	0.96
N2 latency	21.09	0.20
N1-P1 amplitude complex	6.77	0.65
P1-N2 amplitude complex	5.31	1.42

Kruskal-Wallis test was administered to find if there was any significant difference between the latency and amplitude parameters of oVEMP between normal hearing individuals and individuals with vestibular neuritis. Kruskal Wallis test revealed no significant difference in latency or amplitude of oVEMP parameters between normal hearing individuals and 2 individuals with vestibular neuritis for whom the oVEMP responses were present ($p>0.05$).

Caloric test findings

Out of the 6 individuals with VN, 4 ears indicated hypoactive response to caloric stimulation and two ears showed normal response to caloric stimulation. Thus, around 66.67% of the individuals with VN showed hypofunctional and 33.33% indicated normal

response. Figure 4 indicates butterfly charts showing normal, hypoactive and hyperctive responses in individuals with Vestibular Neuritis

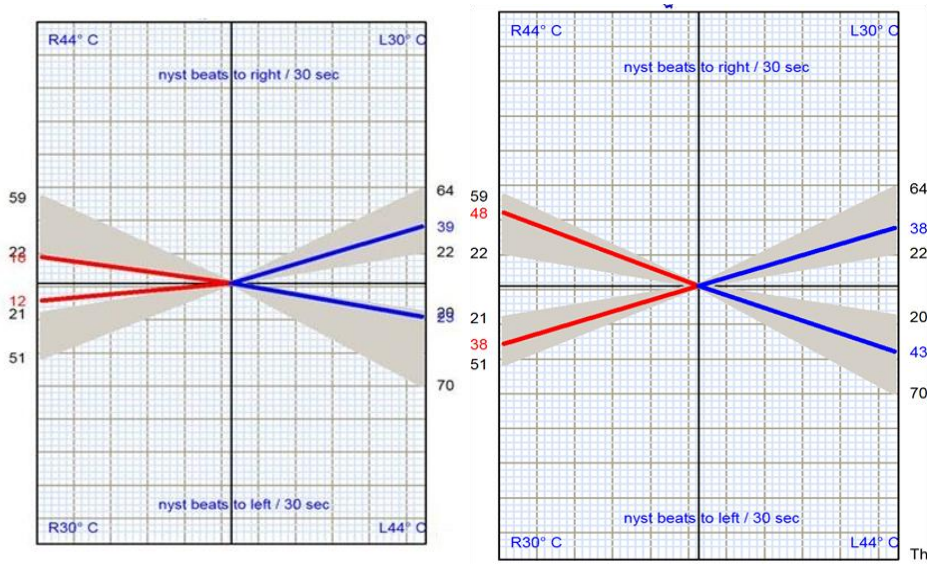

Figure 4. Butterfly charts indicating hypoactive and normal responses on caloric stimulation in individuals with vestibular neuritis

Association of caloric test findings with cVEMPs and oVEMPs in subjects with Vestibular neuritis

The association between different vestibular tests was determined through chi-square test in individuals with vestibular neuritis. The results of the chi-square test have been summarized in table 12.

Table 12

Results of chi-square test indicating the degree of association in individuals with vestibular neuritis

Test		oVEMPs			cVEMPs		
		Present	**Absent**	**Total**	**Present**	**Absent**	**Total**
Caloric test	**Present**	1	1	2	1	1	2
	Absent	1	3	4	4	0	4
	Total	2	4	6	5	1	6
	p value*	1.00			0.33		
cVEMPs	**Present**	2	3	5			
	Absent	0	1	1			
	Total	4	2	6			
	p value*	1.00					

It can be seen from above table that there was no significant association between caloric and cVEMP, cVEMP and oVEMP or oVEMP and Calorics test results in individuals with vestibular neuritis ($p>0.05$).

Vestibular test findings in individuals with BPPV

Total 25 participants with report of BPPV were enrolled for the study. The diagnosis was made based on Dix hallpike test results and also the Otorhinolaryngologist confirmed the diagnosis. The side of the involvement in BPPV subjects (i.e right ear v/s left ear involvement) was also decided based on Dix hallpike test results.

cVEMP findings

Out of 25 ears diagnosed with BPPV, 22 ears had presence of cVEMP responses, whereas other 3 ears had absence of cVEMP responses. Descriptive statistics was carried out to find the mean and standard deviation of latency of p13 and n23 peaks and amplitude of p13-n23 complex. Table 13 indicates the results of descriptive statistics for individuals with BPPV.

Table 13

Results of descriptive statistics on cVEMP parameters in individuals with BPPV

Parameters	**Mean**	**Standard deviation**
p13 latency (msec)	15.85	1.80
n23 latency (msec)	22.58	1.77
Amplitude of p13-n23 complex	35.57	18.73

Kruskal-Wallis test was administered to find if there was any significant difference in latency or amplitude of cVEMP responses between individuals with BPPV and normal participants. Kruskal Wallis test results indicated that there was no significant difference between the two groups for p13 latency ($p>0.05$), n23 latency ($p>0.05$) and also there was no significant difference for p13-n23 amplitude complex ($p>0.05$) between the two groups.

oVEMP findings

oVEMP was present in 14 participants (14 ears) with BPPV whereas in another 11 participants (11 ears) the oVEMP responses were absent. Mean and standard deviation of the p1, n1 and p2 latency and n1-p1 as well as p1-n2 amplitude complexes were calculated through descriptive statistics. The results of the descriptive statistics are summarized in table 14.

Table 14

Results of descriptive statistics showing the mean and standard deviation of parameters of oVEMP in participants with BPPV

Parameters	Mean	Standard Deviation
n1 latency (msec)	12.32	0.91
p1 latency(msec)	16.73	1.05
n2 latency(msec)	20.99	1.36
n1-p1 amplitude complex(µv)	9.30	7.62
p1-n2 amplitude complex(µv)	9.26	7.45

Kruskal-Wallis test was administered to find if there was any significant difference in latency or amplitude of oVEMP responses between individuals with BPPV and normal participants. Kruskal Wallis test results indicated that there was no significant difference between the two groups for n2 latency ($p>0.05$), p1 latency ($p>0.05$) but there was a significant difference in latency for n1 peak between control group and individuals with BPPV ($p<0.05$). Kruskal Wallis test also revealed no significant difference in amplitude for n1-p1complex ($p>0.05$) and p1-n2 complex ($p>0.05$) between control group and individuals with BPPV.

Caloric test findings

Out of the 25 individuals with BPPV (25 ears), 5 ears indicated hypofunctional response for caloric stimulation. Rest of the ears sowed a normal responses. Butterfly charts indicating hypoactive normal responses on caloric stimulation in individuals with BPPV has been illustrated in the figure 5.

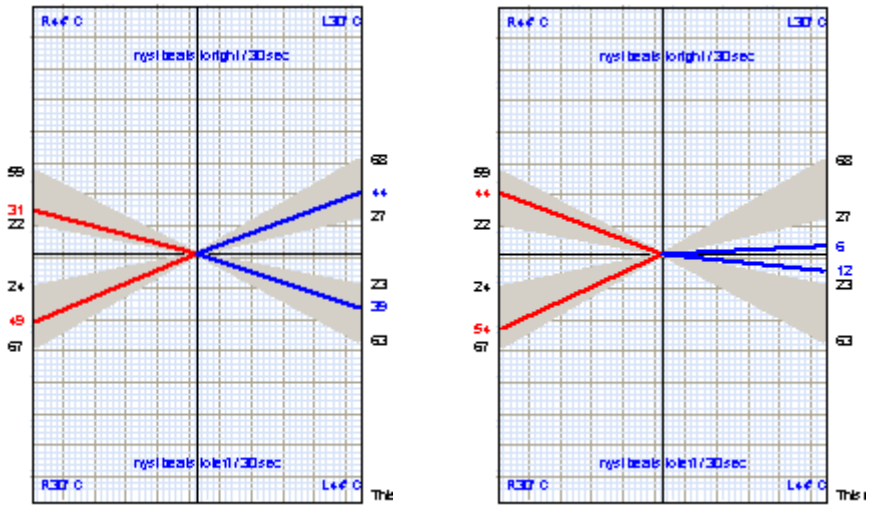

Figure 5. Butterfly charts indicating normal and hypoactive responses on caloric stimulation in individuals with BPPV

Association of caloric test findings with cVEMPs and oVEMPs in the ipsilateral ear of subjects with BPPV

The degree of association of different test results in individuals with BPPV was determined through chi-square test. The table 15 indicates the degree of association between different tests in individuals with BPPV

Table 15

Association between different vestibular tests in individuals with BPPV

Test		**oVEMPs**			**cVEMPs**		
		Normal	**Abnormal**	**Total**	**Normal**	**Abnormal**	**Total**
Caloric test	Normal	12	8	20	20	2	22
	Abnormal	2	3	5	0	3	3
	Total	14	11	25	20	5	25
	p value*	0.42			0.00		
cVEMPs	Normal	14	8	22			
	Abnormal	0	3	03			
	Total	14	11	25			
	p value*	0.037					

It is evident that there was a significant association between cVEMP and caloric test and also between caloric test and oVEMP ($p<0.05$). However, there was no significant association between cVEMP and oVEMP ($p<0.05$) in individuals with BPPV.

Discussion

Meniere's disease:

In the present study, cVEMP responses were absent in 87.87 % of the participants with Meniere's disease whereas, in 69.69% individuals with Meniere's disease the oVEMP responses were absent. In the literature there have been equivocal findings regarding the presence or absence of cVEMP in participants with Meniere's disease. De Waele et al.(1999) have reported a 54% positive rates on cVEMP Murofushi et al. (2001) reported 65% positive rate whereas, Young, Huang and Cheng (2003) reported 88% detection rates in cVEMP for individuals with Meniere's disease. Huang, Wang and Young(2012) reported absence of oVEMP in 44% of the Meniere's disease, whereas, Murofushi et al.(2011) reported absence of oVEMP in 50% of the cases with Meniere's disease. Also, Chivarovano et al. (2011) reported absence of oVEMP in 70% of the cases with Meniere's disease. The differences in different study might be due to the different stage of Meniere's disease. In the early Meniere's disease the VEMP might be present but might disappear at a later stage (Young et al. 2003). All the participants in the present study were diagnosed as having definite Meniere's disease. We assume that all the participants of this study were in the later stage of Meniere's disease.

In this study, the percentage of absence of cervical VEMP was more compared to the ocular VEMP in individuals with Meniere's disease. In individuals with Meniere's disease, during the latent period, ocular VEMP and cervical VEMP could be affected. Katayama et al. (2010) showed with previous MRI data that endolymphatic hydrops distension in the

vestibule has a large effect on the cervical VEMP. Here, the present data also showed that cervical VEMP were more frequently absent than occular VEMP, suggesting that sacular function could be more affected than the utricular function in individuals with Meniere's diseases.

None of the subject with Meniere's disease showed prolonged latency of either cVEMP or oVEMP. Only latency of N1 peak of the cervical VEMP was prolonged for normal hearing individuals compared to the individuals with Meniere's disease. It has been reported that the latency is not affected by saccular or utricular pathology as a result of Meniere's disease as changes in latency are thought to arise from changes in the neural conduction pathways of the sacculo-collic reflex pathway for the cervical VEMP (Kuo, Yang Young (2005) or utricular ocular pathway for oVEMP Chivarovano et al. (2011). However, a neural delay at the level of the receptor organ may contribute to changes in response latency. Studies by Young et al.(2003), Murofushi et al. (2001) and Ochi et al. (2001) have confirmed this and determined that VEMP latency measures are stable in Meniere's disease. Evidence from the cVEMP & oVEMP data in this study supports this theory. The prolongation of N1 peak alone could just be a chance factor.

Hypo activity to caloric stimulation in the affected ear was the most common finding in the present study, which is similar to the studies reported in the literature (Bergman & Stahle 1967). In the present study, 27 out of 33 affected ears (81.81%) showed hypo activity in caloric test. Hypo activity in caloric response could be due to the damage to the hair cells in the horizontal semicircular canal (Murofushi et al. 2011). Five out of 33 ears diagnosed with Meniere's disease had hyperactive responses. The hyperactive caloric responses in patients who suffer from Meniere's disease may be a transient phenomenon, caused by fluctuations of the vestibular condition, central compensation, age and/or mental state of the patients (Ikeda, & Watanabe, 1997).

Other significant results were obtained in the contralateral ears of the individuals with Meniere's disease. In the contralateral ears (n=25) of the individuals with Meniere's disease cVEMP and oVEMP were absent in 5 of the ears, cVEMP was absent and oVEMP was present in 13 of the ears, cVEMP was present and oVEMP was absent in 1 ear, whereas both cVEMP and oVEMP was present in 6 individuals with Meniere's disease. However, the caloric test showed a normal test results in the contralateral ears of individuals with Meniere's disease. Studies in the literature showed that second ear involvement in individuals with unilateral Meniere's disease was seen in 31% to 37% of cases (Thomas & Harrison 1971; Green, Blum & Harner 1991). Study by Lin et al. (2006) found that 27% of participants with unilateral Meniere's disease showed abnormal cVEMP responses in the contralateral ear, which is similar to the present study (Lin et al. 2006).

Histopathological studies of temporal bones of individuals with Meniere's disease showed that hydrops were more common in saccule and utricle compared to the semicircular canal (Okuno & Sando,1987) so it can be concluded that, abnormal cVEMP or oVEMP responses may precede the symptoms in the contralateral ear, so VEMP (cVEMP and oVEMP) responses can be used to predict the chances of involvement of contralateral ear in individuals with Meniere's disease.

In the present study, no statistically significant association between caloric test, cVEMP and oVEMP could be obtained. Significant association only between caloric and oVEMP results, not between caloric and cVEMP or between oVEMP and cVEMP have been reported in peripheral vestibular disorder (Murofushi et al. 2011) It can be hypothesised that the three tests assesses different pathways and extent to which these pathways are affected might vary and hence there might not be any association between the three test results. However, combining caloric test, oVEMP and cVEMP may provide localization of site of lesion in the vestibular labyrinth in affected as well as unaffected ears. The three pathways

are very important as the caloric test assesses the pathway which is responsible for the angular acceleration whereas the utricle and saccule are responsible for the translational movement. All the three pathways are important for balancing, disorder/disease in any of the pathway cal lead to dysbalance.

Vestibular Neuritis:

Out of 6 participants with vestibular neuritis, 5 participants had presence of response on cVEMP (83.33%), whereas one participant had and absence of cVEMP response (16.67%). Studies which have utilized cVEMP to assess the functioning of saccule and inferior vestibular nerve have also reported an absent cVEMP in individuals with vestibular neuritis. For example, Murofushi et al. (2001) reported abnormal cVEMPs findings in 39 % of the individuals with vestibular neuritis, Hong et al. (2008) reported abnormal cVEMP response in 36.6% of the subjects with vestibular neuritis whereas, Chiarovano, Zamith, Vidal and Waele (2011) reported 66.67% of participants showed abnormal cVEMPs responses in their study. Murofushi et al. also (2011) reported that in 33.33% of the subjects with vestibular neuritis cVEMP is affected, Sarvanan (2011) also reported abnormal cVEMP findings in 40% of the vestibular neuritis subjects. Percentage of abnormality obtained in the present study are lesser compared to the previous studies. As it has been reported that the vestibular neuritis affect either superior vestibular nerve or inferior vestibular nerve or both the nerve, the differences in different study might be due to involvement of different branches of vestibular nerve in individuals with vestibular neuritis (Aw et al.2006). That is subjects assessed in the present study might have lesser involvement of inferior vestibular nerve compared to the superior vestibular nerve.

4 individuals had absent oVEMP response i.e., 66.67% of the individuals with vestibular neuritis had absence of oVEMP whereas, 2 subjects (33.33%) had present oVEMP responses. Some of the previous studies such as Chiaravano et al. (2011) have reported 75% abnormal

oVEMPs responses in individuals with vestibular neuritis and Murofushi, Nakahara, Yoshimura & Tsuda (2011) have reported abnormal oVEMPs responses in 100% of the individuals with vestibular neuritis. Other studies have reported Variability in the results of different studies might me due to variable sample size and variable involvement of different branches of vestibular nerve in individuals with vestibular neuritis (Aw et al. 2006). The percentage of oVEMP abnormality was more in individuals with vestibular neuritis compared to the cVEMP. It has been reported that the vestibular neuritis mainly affects the superior vestibular nerve (Chiarovono et al. 2011) than the inferior vestibular nerve. Since the oVEMP mainly assess the superior vestibular nerve it is expected that the oVEMP abnormality will be more compared to the cVEMP in individuals with vestibular neuritis.

4 out of 6 ears showed, hypo activity caloric stimulation which is the most common findings reported in the vestibular neuritis (Wennmo & Pyykko, 1982; Sarvanan, 2011). Hypo activity in caloric test indicates damage to the superior branch of vestibular nerve innervating horizontal semicircular canal (Wennmo & Pyykko, 1982; Sarvanan 2011).

Also the results showed that there was no significant association between calorics & cVEMP, cVEMP & oVEMP, and calorics and oVEMP test in individuals with vestibular neuritis. Previously a strong association between the oVEMP and caloric test has been reported in various peripheral vestibular pathology (Murofushi et al. 2011). In the present study, there was no association between the caloric test and oVEMP test. No association between calorics and oVEMP tests in vestibular neuritis could be due to the smaller sample size in the present study. A larger data probably would have reflected any significant association. Also, there was no association between cVEMP and oVEMP test in individuals with vestibular neuritis. No association between cVEMP and oVEMP could be due the fact that the tests assess different pathways and also different mechanisms (Chiarovono et al. 2011).

Benign Paroxysmal positional vertigo

In subjects with BPPV out of 25 ears diagnosed with BPPV, 22 ears had presence of cVEMP responses, whereas other 3 ears had absence of cVEMP responses. Previous studies have also revealed abnormal findings in individuals with BPPV. For example, Hong, Park, Yeo and Cha (2008) studied cVEMP responses in BPPV and reported that 13/53 subjects with BPPV (24.5%) showed abnormal cVEMP responses in the affected side than the age match control group. Hong, Yeo, Kim and Cha (2008) also studied cVEMP responses in 62 individuals with BPPV and reported that 16 subjects (25.8%) had abnormal cVEMP findings. Akkuzu, Akkuzu & Ozlouglu, (2006) also reported an abnormal cVEMP findings in around 15% of the subjects with BPPV. In the present study only 12% of the participants with BPPV had absent cVEMP, which is slightly lesser than reported earlier. The absence of cVEMP in individuals with BPPV could be due to the secondary changes occurring in saccular macula or its innervating structures due to displacement of otocornia (Akkuzu, Akkuzu & Ozlouglu, 2006; Hong, Yeo, Kim and Cha, 2008)

oVEMP was present in 14 participants (14 ears,56%) with BPPV whereas in another 11 participants (11 ears, 44%) the oVEMP responses were absent. Previous studies have also reported an absence of oVEMP in 52 to 86% of the participants with BPPV (Akkuzu, Akkuzu & Ozlouglu, 2006;Yang, Kim, Lee & Lee, 2008). In the present study also, in 44% of the participants with BPPV had an absence of oVEMP in individuals with BPPV. The reason for the absent oVEMP responses has been attributed to the neuronal degenerative changes in the macula of the utricle. Also it was suggested that a "no-response" on oVEMP was related to extensive neuronal damage which accompanies the disease when it takes a chronic and resistive course (Korres et al., 2008).

In the present study, 5 ears (20%) indicated hypofunctional response for caloric stimulation and rest 20 participants (20ears) had normal caloric test findings. Caloric test

results abnormalities are quite common in individuals with BPPV. Korres, Balatsouras, and Ferakidis (2004) studied caloric test results in one hundred fifty-one patients with involvement of the posterior canal and reported that Seventy-two patients (42.8%) had abnormal findings on the caloric tests. Thirty-seven of them (22%) had canal paresis and 23 (13.7%) had directional preponderance, whereas in 12 patients (7.1%) both unilateral weakness and directional preponderance were found. Wu et al. (2006) also reported an abnormal caloric test results findings in 28% of the individuals with BPPV whereas Molina et al. (2007) reported reduced responses in 25% of the subjects with BPPV.

The caloric test findings of the present study reveals an impairment of the superior vestibular nerve in subjects with BPPV as the caloric test only assesses the lateral canal. Therefore, the caloric test must be performed in individuals with BPPV to assess the condition of the superior vestibular nerve. The changes in superior vestibular nerve might be starting from the connections from utricle and slowly extending to the ending which are connected to the lateral canal (Molina et al. 2007).

In the present study there was a correlation between oVEMP and the caloric test and also the cVEMP and the caloric test results. However there was no association between cVEMP and oVEMP test findings in individuals with BPPV. Previously a strong association between the oVEMP and caloric test has been reported in various peripheral vestibular pathology (Murofushi et al. 2011). An association between the oVEMP and caloric test is expected as both the test assess the superior vestibular nerve (Sarvanan, 2011). No association between cVEMP and oVEMP could be due the fact that the tests assess different pathways and also different mechanisms (Chiarovono et al. 2011).

Conclusions

Caloric test, cVEMPs and oVEMPs mainly assesses the functioning of semi circular canal, sacculo-collic pathway and utriculo-ocular reflex pathway respectively. In vestibular

dysfunction, one or more reflex pathways are affected. Since the above 3 tests assess the functioning of 3 different pathways, the combination of caloric test, cVEMPs and oVEMPs provides valuable information regarding localization of lesions in various peripheral vestibular disorders.

Reference

Akkuzu, G., Akkuzu, B., Ozluoglu, L. N. (2006). Vestibular evoked myogenic potentials in benign paroxysmal positional vertigo and Meniere's disease. *Eur Arch otorhinolaryngol, 263*, 510-517.

American National Standards Institute (1991). *American National Standards for maximum permissible ambient noise levels for audiometric test room*. (ANSI S3.1- 1991). New York: American National Standards Institute.

American National Standards Institute. (1991). *American National Standards for maximum permissible ambient noise levels for audiometric test room* (ANSI S3.1- 1991). New York: American National Standards Institute.

Aw, S. T., Magnussen, J. S., Todd, M. J., et al. (2006). MRI of the vestibular nerve after selective vestibular neurectomy. *Acta Otolaryngol, 126*, 1053-1056.

Bakr, M. S., Saleh, E. M. (2000). Electronystagmography: how helpful is it? *J Laryngol Otol, 114*, 178-183.

Bergman, B., Stahle, J. (1967). Caloric Reaction in Menière'sDisease.A Nystagmographic Study of 300 Patients. *Acta Oto Laryngol Suppl, 63*, 77-79

Bhansali, S. A., Honrubia, V. (1999). Current status of electronystagmography testing. *Otolaryngol Head Neck Surg, 120*, 419-426.

Boleas-Aguirre, M., Sanchez-Ferrandiz, N., Artieda, J., et al. (2007). [Vestibular evoked myogenic potentials and benign paroxysmal positional vertigo]. *Acta Otorrinolaringol Esp, 58*, 173-177.

Chiarovano, E., Zamith, F., Vidal, P. P., et al. (2011). Ocular and cervical VEMPs: a study of 74 patients suffering from peripheral vestibular disorders. *Clin Neurophysiol, 122*, 1650-1659.

Chihara, Y., Iwasaki, S., Ushio, M., et al. (2009). Ocular vestibular-evoked myogenic potentials (oVEMPs) require extraocular muscles but not facial or cochlear nerve activity. *Clin Neurophysiol, 120,* 581-587.

Claussen, C.F., Von Schlachta, I. (1972) Butterfly chart for caloric nystagmus evaluation. *Archives Otolaryngol, 96,*371–375.

Coats, A. C. (1970). Central electronystagmographic abnormalities. *Arch. Otolaryngol, 92,* 43–53.

Colledge, N.R., Barr-Hamilton, R. M., Lewis, S. J., et al. (1997). Evaluation of investigations to diagnose the cause of dizziness in elderly people: a community based controlled study. *British Med. J, 313,* 788–789.

De Waele, C., Huy, P.T., Diard, J.P. (1999) Saccular dysfunction in Meniere's disease. *Am J Otolaryngol 20(2),* 223-232.

Goodhill, V. (1979). *Ear diseases, deafness and dizziness.* Haggerstown, Maryland: Harper and Row.

Green, J.D., Blum, D.J, Harner, S.G. (1991). The longitudinal follow up of patients with Meniere's disease. *Otolaryngol Head Neck Surg 104(6),* 783-788.

Halmagyi, G. M., Curthoys, I. S. (1999). Clinical testing of otolith function. *Ann N Y Acad Sci, 871,* 195-204.

Hong, S. M., Park, D. C., Yeo, S. G., et al. (2008). Vestibular evoked myogenic potentials in patients with benign paroxysmal positional vertigo involving each semicircular canal. *Am J Otolaryngol, 29,* 184-187.

Hong, S. M., Park, D. C., Yeo, S., et.al. (2008).Vestibular evoked myogenic potentials in patients with benign paroxysmal positional vertigo involving each semicircular canal. *Am J Otolaryngol, 29,* 184-187.

Hong, S. M., Yeo, S. G., Kim, S. W., et al. (2008). The results of vestibular evoked myogenic potentials, with consideration of age-related changes, in vestibular neuritis, benign paroxysmal positional vertigo, and Meniere's disease. *Acta Otolaryngol, 128*, 861-865.

Hong, S. M., Yeo, S. G., Kim, S. W., et al. (2008). The results of vestibular evoked myogenic potentials, with consideration of age-related changes, in vestibular neuritis, benign paroxysmal positional vertigo, and Meniere's disease. *Acta Otolaryngol, 128*, 861-865.

Huang, C. H., Wang, S. J., Young, Y. H. (2012). Correlation between caloric and ocular vestibular evoked myogenic potential test results. *Acta Otolaryngol, 132*, 160-166.

Huang, C. H., Wang, S. J., Young, Y. H. (2012). Correlation between caloric and ocular vestibular evoked myogenic potential test results. *Acta Otolaryngol, 132*, 160-166.

Ikeda, M., Watanabe, I. (1997) Evaluation of hyperactive responses in inner ear diseases. J *Otorhinolaryngol Relat Spec*, 59(6), 326-331.

Jacobson, G. P., McCaslin, D. L., Piker, E. G., et al. (2011). Patterns of abnormality in cVEMP, oVEMP, and caloric tests may provide topological information about vestibular impairment. *J Am Acad Audiol, 22*, 601-611.

Katayama, N., Yamamoto, M., Teranishi, M., et al. (2010) Relationship between endolymphatic hydrops and vestibular evoked myogenic potential. *Acta Otolaryngol, 130(8),* 917-923.

Kirtane, M. V., Medikeri, S. B., Merchant, S. N., et al. (1985). Electronystagmography findings in acoustic neuromas. *J Postgrad Med, 31*, 128-133.

Korres, S. G., Balatsouras, D. G., &Ferakidis, E. (2004). Electronystagmographic findings in benign paroxysmal positional vertigo. *Annals Otol, Rhinol Laryngol, 113*, 313-318.

Kumar, K., Sinha, S. K., Bharti, A. K., et al. (2011). Comparison of vestibular evoked myogenic potentials elicited by click and short duration tone burst stimuli. *J Laryngol Otol, 125*, 343-347.

Kuo, S. W., Yang, T. H., Young, Y. H. (2005). Changes in vestibular evoked myogenic potentials after Meniere attacks. *Ann Otol Rhinol Laryngol, 114*, 717-721.

Lin, M., Timmer, F.C.A., Oriel, B.S., et al. (2006). Vestibular evoked myogenic potentials (vemp) can detect asymptomatic saccular hydrops. *Laryngoscope, 116,* 987- 992.

Molina, M., Jose, A., Zapata,C., et a. (2007). Monitoring of Caloric Response and Outcome in Patients With Benign Paroxysmal Positional Vertigo. Otol Nerootol, 28:798-800

Murofushi, T., Nakahara, H., Yoshimura, E., et al. (2011). Association of air-conducted sound oVEMP findings with cVEMP and caloric test findings in patients with unilateral peripheral vestibular disorders. *Acta Otolaryngol, 131,* 945-950.

Murofushi, T., Nakahara, H., Yoshimura, E., et al. (2011). Association of air-conducted sound oVEMP findings with cVEMP and caloric test findings in patients with unilateral peripheral vestibular disorders. *Acta Otolaryngol, 131*, 945-950.

Murofushi, T., Shimizu, K., Takegoshi, H., et al. (2001). Diagnostic value of prolonged latencies in the vestibular evoked myogenic potential. *Arch Otolaryngol Head Neck Surg, 127*, 1069-1072.

Murofushi, T., Shimizu, K., Takegoshi, H., et al. (2001). Diagnostic value of prolonged latencies in the vestibular evoked myogenic potential. *Arch Otolaryngol Head Neck Surg, 127*, 1069-1072.

Ochi, K., Ohashi, T. (2001). Sound-evoked myogenic potentials and responses with 3-ms latency in auditory brainstem response. *Laryngoscope, 111*, 1818-1821.

Ojala, M., Vaheri, E., Juntenen, J. (1989). Electronystagmographic findings among 127 dizzy patients: correlation with the aetiology of dizziness. *Clin Otolaryngol, 14*, 343-348.

Okuno, T., Sando, I. (1987). Localization, frequency and severity of endolymphatic hydrops and the pathology of the labyrinthine membrane in Meniere's disease. *Annals of Otol, Rhinol and Laryngol, 96,* 438-445.

Pflatz, C.T. (1984). Limits and possibilities of electronystagmography. *Laryngol Rhinol Otol, 63*, 511–516.

Rosengren, S. M., McAngus Todd, N. P., Colebatch, J. G. (2005). Vestibular-evoked extraocular potentials produced by stimulation with bone-conducted sound. *Clin Neurophysiol, 116*, 1938-1948.

Rosengren, S. M., Welgampola, M. S., Colebatch, J. G. (2010). Vestibular evoked myogenic potentials: past, present and future. *Clin Neurophysiol, 121*, 636-651.

Sarvanan, P. (2011). Assessment of different vestibular pathways in individuals with dizziness. Unpublished dissertation submitted to the University of Mysore, Mysore.

Shi, M., Yu, X., Niu, H., et al. (1997).The value of electronystagmography in differential diagnosis of vertigo. *Bull Hum Med Uni, 22,* 156-158.

Sinha, S. K., Barman, A., Singh, N. K., et al. (2013). Involvement of peripheral vestibular nerve in individuals with auditory neuropathy. *Eur Arch Otorhinolaryngol, 270,* 2207-2214.

Thomas, K., Harrison, M.S. (1971). Long term follow up of 610 cases of Meniere's disease. *Proc R Soc Med 64(8),* 853-856.

Todd, N. P., Rosengren, S. M., Aw, S. T., et al. (2007). Ocular vestibular evoked myogenic potentials (OVEMPs) produced by air- and bone-conducted sound. *Clin Neurophysiol, 118*, 381-390.

Welgampola, M. S., Migliaccio, A. A., Myrie, O. A., et al. (2009). The human sound-evoked vestibulo-ocular reflex and its electromyographic correlate. *Clin Neurophysiol, 120,* 158-166.

Wennmo, C., & Pyykko, I. (1982). Vestibular neuronitis: A Clinical and Electro-oculogruphic Analysis. *Acta Otolaryngol, 94*, 507-515.

Wu, Z. M., Zhang, S. Z., Zhou, N., et al. (2006). [Audio-vestibular function in patients with benign paroxysmal positional vertigo]. *Zhonghua Er Bi Yan Hou Tou Jing Wai Ke Za Zhi, 41*, 669-672.

Yang, W., Kim, S. H., Lee, J. D., & Lee, W. (2008). Clinical significance of vestibular evoked myogenic potentials in benign paroxysmal positional ertigo. *Otol.Neurotol, 29*, 1162-1166.

Young, Y. H., Huang, T. W., Cheng, P. W. (2003). Assessing the stage of Meniere's disease using vestibular evoked myogenic potentials. *Arch Otolaryngol Head Neck Surg, 129*, 815-818.