Hindawi Publishing Corporation
Advances in Otolaryngology
Volume 2015, Article ID 978161, 11 pages
http://dx.doi.org/10.1155/2015/978161

Research Article

Relative Efficiency of Cochlear Hydrops Analysis Masking Procedure and Cervical Vestibular Evoked Myogenic Potential in Identification of Meniere's Disease

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Received 25 June 2014; Revised 10 December 2014; Accepted 4 February 2015

Academic Editor: Neil Bhattacharyya

Cervical vestibular evoked myogenic potential (cVEMP) and cochlear hydrops analysis masking procedure (CHAMP) have both shown sensitivity in identifying Meniere's disease. However none of the previous reports have compared the two tests for their relative efficacy in identifying Meniere's disease. Hence the present study aimed to compare the efficiency of cVEMP and CHAMP in evaluating Meniere's disease. The study included 58 individuals with unilateral definite Meniere's disease and an equal number of age and gender matched healthy individuals. cVEMP corresponding to 500 Hz tone burst was recorded from ipsilateral sternocleidomastoid muscle and CHAMP was acquired from the conventional electrode sites for single channel auditory brainstem response recording using a default protocol of the Biologic Navigator Pro evoked potential system. Both cVEMP and CHAMP showed statistically significant differences between the groups ($P < 0.05$). The receiver operating curves revealed 100% sensitivity and specificity for CHAMP as against 70.7% sensitivity and 100% specificity for cVEMP in identifying Meniere's disease. Therefore, CHAMP appears to be the test of choice provided the degree of hearing loss does not exceed a moderate degree. cVEMP could be used for all degrees of hearing losses, but with slight constraint on the sensitivity.

1. Introduction

Meniere's disease is a progressive idiopathic disorder of the inner ear, which may result in degeneration of cochlear and vestibular hair cells. It was first described by Prosper Meniere in 1861 and since then it has been noted as one of the most common disorders of the vestibular system [1]. It is characterized by the symptom triad of fluctuating sensorineural hearing loss, tinnitus, and vertigo [2]. The other symptoms include aural fullness, nausea, and vomiting [3].

The cause of Meniere's disease is a source of curiosity and still remains controversial. Trauma [4], viral vestibular ganglionitis [5], and genetic predisposition [6] are among the most popular theories explaining the cause of Meniere's disease. Other researchers suspect pathologies of the stria vascularis to be responsible for the symptom complex in Meniere's disease [7]. Still others believe it to be a possible autoimmune disorder [8]. Irrespective of the beliefs regarding the causative factors, the etiology of Meniere's symptoms has been shown to be an abnormal increase in endolymph volumes in the inner ear [9–12].

The disagreement among the scholars regarding a definitive causative factor for Meniere's disease adds up to the complex nature of the disease and increases the challenges posed upon clinicians towards its accurate identification. This, in addition to the high prevalence, has probably led to the trial of several tests for identifying Meniere's disease ever since its identification. These include pure-tone audiometry, immittance, posturography, glycerol test, and electrocochleography (ECochG). The sensitivity of these tests ranges from 37% to 61%, whereas the specificity ranges from 51% to 89%, with most falling below 65%, except posturography at 89% [13, 14]. Lower sensitivity and specificity than desired make the above mentioned tests erratic for diagnosis, thus making the administration of appropriate diagnostic tools a challenging task. This has resulted in continued exploration of new tests for diagnosing Meniere's disease. More recently, cervical vestibular evoked myogenic potentials [15, 16] and cochlear hydrops analysis masking procedure [17] have been reported as promising tests for the identification of Meniere's disease induced changes in the audiovestibular periphery.

Cervical vestibular evoked myogenic potential (cVEMP) is a test for evaluating the functional integrity of the saccule [18]. This sound-induced potential is produced along the sacculocolic reflex pathway [18–20]. The sound-induced electrical impulses, which predominantly originate in the saccule with some contributions from utricle and the semicircular canal, move along the vestibular apparatus through the inferior vestibular nerve and reach the sternocleidomastoid (SCM) muscle via the vestibulospinal tract [18–20]. The recorded response from the sternocleidomastoid muscle is a biphasic potential consisting of both positive and negative waves, where the positive wave is termed as P13 or P1 and the negative one as N23 or N1 [18]. cVEMP has been found to be useful in the identification of several vestibular pathologies including Meniere's disease. Findings such as reduced amplitude [21–27] and increased asymmetry ratio [25, 28] of cVEMP have been reported in individuals with Meniere's disease.

The endolymphatic hydrops, the most widely accepted etiologic factor behind Meniere's disease, has been reported to alter the stiffness properties of the basilar membrane and increased fluid column height which is believed to cause increased propagation speed of the travelling wave within the cochlea [29, 30]. Based on these unique changes in the inner ear dynamics, a noninvasive procedure known as cochlear hydrops analysis masking procedure (CHAMP) was introduced as a clinical tool to differentiate Meniere's disease from other vestibular pathologies [17]. CHAMP assesses the cochlear properties, especially of the basilar membrane, by using the principle of latency changes in ABR to click stimuli caused by the presence of progressively reduced cut-off frequency of high-pass masking noise. The undermasking caused by presence of Meniere's disease results in a much lesser difference in wave V latency of ABR between unmasked (response to click alone) and masked (response to clicks in the presence of high-pass masking with cut-off at 500 Hz) conditions of responses [17].

CHAMP and cVEMP have both been extensively explored and largely reported to be useful in identifying Meniere's disease. The sensitivity of cVEMP in identifying Meniere's disease has been reported to range from 53% to 94% [24, 31]. In terms of CHAMP, Don et al. reported 100% sensitivity and specificity in identifying Meniere's disease [17]. However, some of the other studies have questioned these findings by reporting significantly lower sensitivity and specificity values [32, 33]. While de Valck et al. reported 31% sensitivity and 28% specificity, Kingma and Wit showed 32% sensitivity using the standard criteria of <0.3 ms latency difference between click alone and click + 500 Hz high-pass masking noise [31, 32]. Thus there appears to be a wide range of sensitivity and specificity values for both the potentials. This indicates a need for continued exploration of these tests in order to establish the usefulness or lack of it in the diagnosis of Meniere's disease using these tests. Further, these studies have been conducted at different places using variable protocols and subjects. Therefore the sensitivity and specificity values for the two potentials cannot be compared directly. There is also a dearth of studies comparing these procedures on the same set of individuals for examining their relative efficacy in identifying Meniere's disease. Therefore, the present study is aimed at comparing cVEMP and CHAMP for evaluating their efficiency in identifying Meniere's disease on the same group of individuals.

2. Method

2.1. Participants. The present study was conducted in accordance with the declaration of Helsinki [34]. The study used 58 participants (30 males and 28 females) in the age range of 20 to 50 years (mean age = 35.2 years, standard deviation = 4.6) diagnosed with unilateral definite Meniere's disease as participants of the clinical group. Diagnosis of definite Meniere's disease was based on the criteria laid out by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology-Head and Neck Surgery [35]. As per these criteria, the diagnosis of definite Meniere's disease requires an individual to experience two or more definitive spontaneous episodes of vertigo lasting over 20 minutes, documented hearing loss using audiometric procedures on at least one occasion, tinnitus, or aural fullness in the affected ear with other causes of such precipitations ruled out. The control group consisted of 58 healthy individuals (30 males and 28 females) in the age range of 20 to 50 years (mean age = 35.2 years, standard deviation = 4.6) with normal audiovestibular system which was ascertained by normal results on pure-tone audiometry (hearing thresholds within 15 dB HL for both air- and bone-conduction modes), type "A" tympanogram with acoustic reflex threshold within 100 dB HL at octave frequencies from 500 to 2000 Hz, presence of otoacoustic emissions, and indication of no retrocochlear pathology on auditory brainstem responses.

2.2. Procedure. Biologic Navigator Pro (version 7.0.0) evoked potential system (Illinois, USA) was used for recording CHAMP and cVEMP responses. Both the evaluations were carried out in acoustically treated single room suites with ambient noise levels meeting the requirements of ANSI standards [36].

2.2.1. Recording of Cervical Vestibular Evoked Myogenic Potentials. For the purpose of recording cVEMP, the participants were seated on a straight back chair. The recording of cVEMP was performed using the conventional electrode montage used previously [22, 37–40]. As per this, the noninverting electrode was placed over the middle part of the body of SCM muscle, inverting at the sternoclavicular junction and the ground on the forehead. During the recording of the responses, the participants were instructed to rotate their heads away from the ear of auditory stimulation in order to activate the sternocleidomastoid muscle. The muscle tension was maintained at a constant level within and between subjects by ensuring a constant target pointer on the shoulder resulting in about 60–70° head rotation from the midline in a direction opposite to the ear of acoustic stimulation. This method has been shown to produce similar values of variability to the use of an LED device for visual feedback and systems using electromyographic normalization [41]. It has also been shown to produce similar or better test-retest reliability than the use of an LED device for visual feedback [42, 43]. Using the etymotic ER-3A insert earphones of the Biologic Navigator Pro evoked potential system, alternating polarity 500 Hz tone-bursts were presented at an intensity of 125 dB SPL. The stimuli were grated using 2 ms rise/fall time and 1 ms plateau time as found optimum previously [39]. The stimuli were presented at a rate of 5.1 Hz. Responses from 200 stimuli were averaged to produce each waveform.

2.2.2. Recording of Cochlear Hydrops Analysis Masking Procedure. CHAMP was recorded with the participants seated in a comfortable position on a reclining chair. The recording of CHAMP involved placement of noninverting electrode on the vertex, inverting on the mastoid of the test ear and the ground electrode on the mastoid of the opposite ear (nontest ear), similar to those used in the previous studies [17, 32, 36]. The default settings of the Biologic Navigator Pro evoked potential system were used for recording CHAMP. Rarefaction polarity 60 dB nHL clicks were presented through a broadband insert 580-BINSER at a repetition rate of 45.5/s and averaged over 9200 stimuli. Responses were obtained for click alone and click with different ipsilaterally presented high-pass masking pink noises (81 dB SPL) with cut-off at octave frequencies from 8000 to 500 Hz (8000, 4000, 2000, 1000, and 500 Hz). An epoch of 16 ms was used in order to avoid un-ABR like responses that might arise beyond a latency of 16 ms. These responses were band-pass filtered between 0.1 Hz and 3000 Hz. A total of 6 responses were recorded: one for click alone stimulus condition and the remaining five corresponding to click along with each of the 5 high-pass masking noises. The responses were recorded twice for each stimulation condition in order to ensure reproducibility of the response.

3. Results

The present study compared cVEMP and CHAMP in order to arrive at the conclusion of a better test among the two for identifying Meniere's disease. In order to fulfill the objectives of the present study, 58 individuals with Meniere's disease were compared with an equal number of age and gender matched healthy individuals on cVEMP and CHAMP.

3.1. Cervical Vestibular Evoked Myogenic Potentials. Cervical VEMP were obtained from both ears of 58 individuals with Meniere's disease and same number of age and gender matched healthy individuals. The obtained waveforms were analyzed morphologically for peak-to-peak amplitude and asymmetry ratio. Figure 1 shows representative cVEMP waveforms recorded from an individual with unilateral definite Meniere's disease and an age and gender matched healthy individual.

Descriptive statistics was done to obtain mean and standard deviation of peak-to-peak amplitude and asymmetry ratio of cVEMP in individuals with Meniere's disease as well as healthy individuals. The lowest amplitudes were obtained in the affected ears with Meniere's disease followed by their unaffected ears. The individuals with Meniere's disease also portrayed larger asymmetry ratios than their healthy counterparts. The results of the descriptive statistics are shown in Table 1.

The statistical significance of the above observations for amplitude was evaluated using one-way repeated measures ANOVA for ears with group as the between subject factor (mixed ANOVA). The results demonstrated a significant main effect of ear [$F(1, 114) = 6.141$, $P < 0.05$] and group [$F(1, 114) = 22.035$, $P < 0.05$], but no significant interaction between ear and group [$F(1, 114) = 3.209$, $P > 0.05$]. Although the mixed ANOVA shows significant main effect of ear as well as group, it does not shed light on ear differences within each group and also group difference for each type of ear (Meniere's affected ears and unaffected ears). In order to evaluate the existence of difference between the ears within each group, separate paired t-tests were administered for each group and for identifying the presence of differences between the groups for each type of ear, independent samples t-test were done. Due to multiple t-tests, appropriate Bonferroni corrections were incorporated for the levels of significance. The results of paired t-test revealed significant difference between the ears in group of individuals with Meniere's disease [$t(57) = -3.106$, $P < 0.025$] but not in the groups of healthy individuals [$t(57) = 0.473$, $P > 0.025$]. The results of independent samples t-test revealed a significant difference between both, Meniere's affected ears and the matched ears of healthy individuals [$t(114) = -4.891$, $P < 0.025$] as well as the unaffected ears of individuals with Meniere's disease and matched ears of healthy individuals [$t(114) = -2.523$, $P < 0.025$]. These comparisons have been depicted in Figure 2 as box-plots. An independent samples t-test was also administered for asymmetry ratio comparison between the groups. The results revealed significant difference between the groups [$t(114) = 8.796$, $P < 0.05$]. Figure 2 also shows the box-plots of asymmetry ratio of cVEMP for both the groups.

Thus, the results of cVEMP were suggestive of significantly smaller amplitude and larger asymmetry ratio in Meniere's disease compared to healthy individuals. Although the participants were unilaterally affected with Meniere's disease, the results revealed significantly smaller amplitude of cVEMP even in the unaffected ears of individuals with Meniere's disease when compared to age and gender matched healthy individuals group.

3.2. Cochlear Hydrops Analysis Masking Procedure. CHAMP responses were obtained from all the 58 individuals with unilateral definite Meniere's as well as their healthy controls. Figure 3 shows CHAMP waveforms obtained for click alone and click with ipsilaterally presented high-pass masking pink noise with cut-off at 500 Hz.

Descriptive statistics was carried out in order to obtain mean and standard deviation values for latency difference

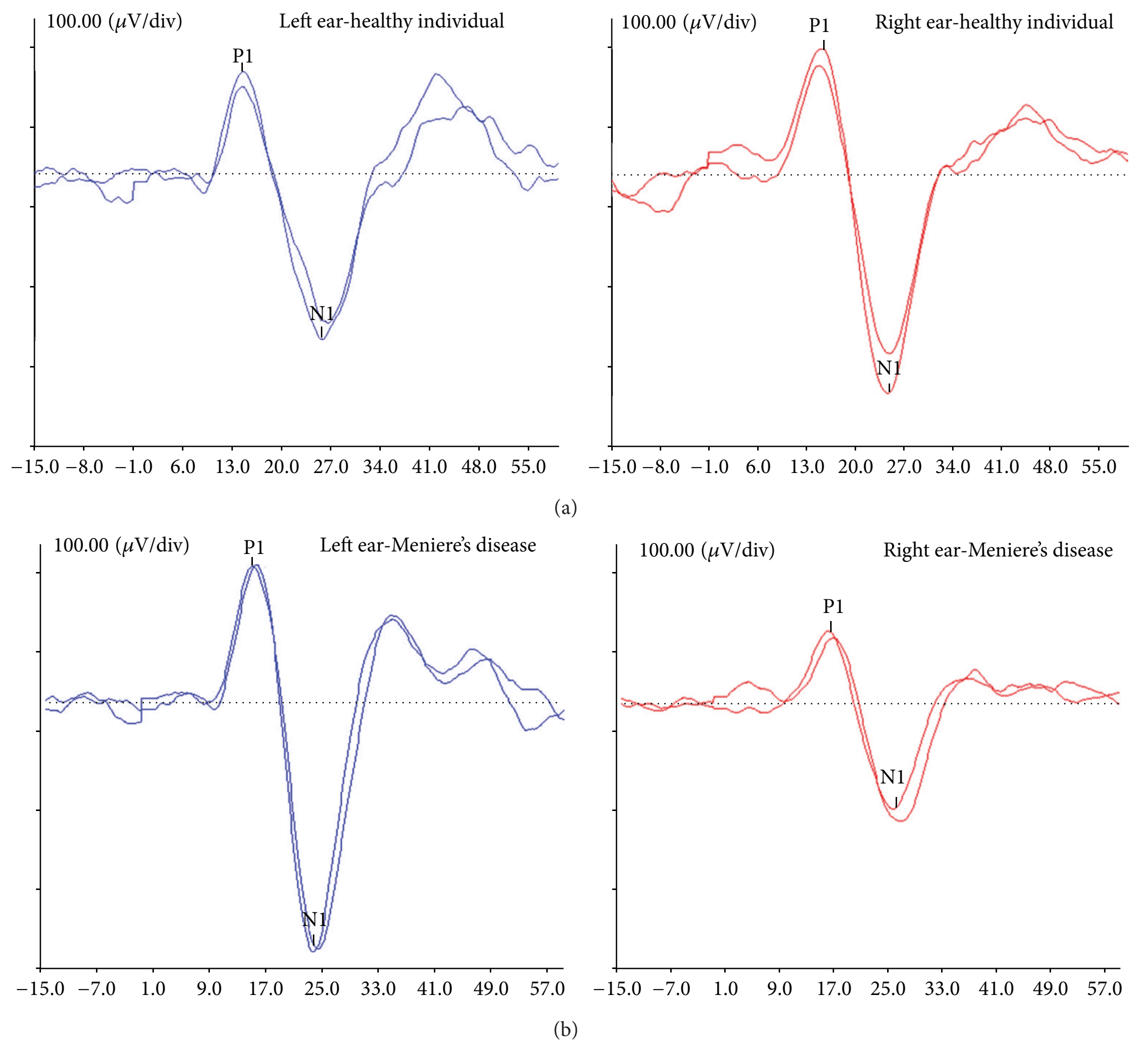

Figure 1: Representative cervical vestibular evoked myogenic potentials waveforms recorded from an individual with unilateral Meniere's disease (bottom panels) and an age and gender matched healthy individual (top panels). In this individual with Meniere's disease, right ear was the pathological ear. The positivity is indicated upwards.

Table 1: Mean and standard deviation for amplitude and asymmetry ratio of cervical vestibular evoked myogenic potentials and latency difference of wave V between click alone and click with 500 Hz high-pass masking pink noise in healthy individuals and individuals with Meniere's disease.

Population		cVEMP		CHAMP
		Amplitude (in μV)	Asymmetry ratio (in %)	Wave V latency difference (in ms)
Individuals with Meniere's disease	Affected ear	106.96 (74.00)	42.78 (22.48)	0.14 (0.10)
	Unaffected ear	124.92 (60.96)		0.89 (0.11)
Healthy individuals	Affected matched	151.31 (63.74)	16.19 (4.90)	0.96 (0.17)
	Unaffected matched	154.20 (63.99)		0.93 (0.15)

Note: "affected matched" and "unaffected matched" ears in healthy individuals are referred to the same side ears of the healthy individuals as that of individuals with Meniere's disease that were affected and not affected by the disease, respectively. The values within the brackets represent standard deviation.

between click alone condition and click along with ipsilaterally presented high-pass masking pink noise with cutoff at 500 Hz obtained from healthy individuals as well as individuals with Meniere's disease. Lowest mean difference was observed in the affected ears of individuals with Meniere's disease and largest difference between the stimulus conditions was obtained for ears of healthy individuals. The results of descriptive statistics are shown in Table 1.

The statistical significance of the above mentioned observation was evaluated using one-way repeated measures

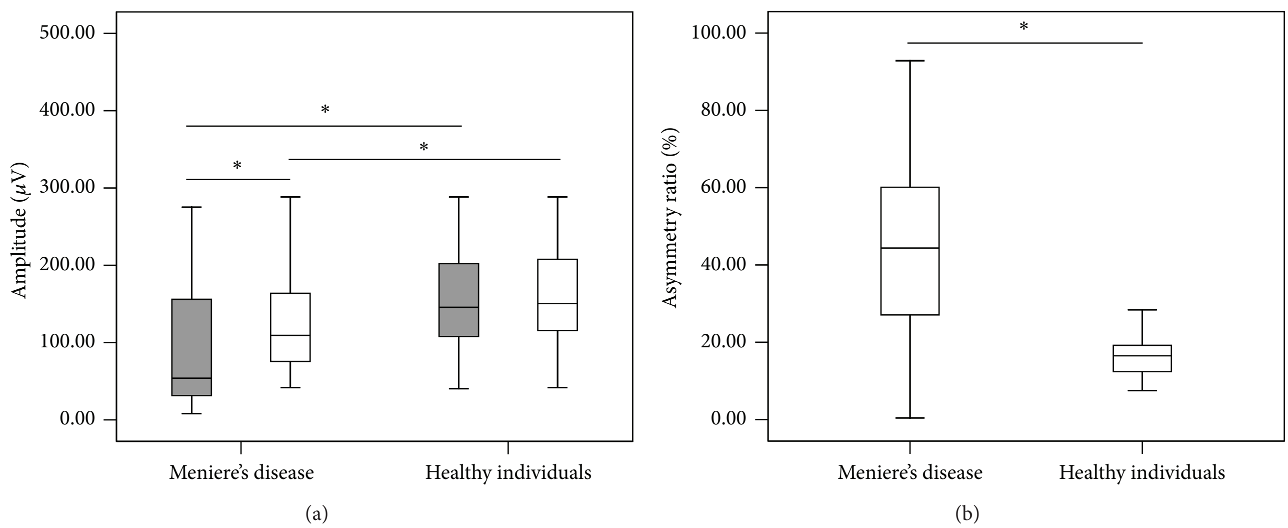

Figure 2: Box-plots for peak-to-peak amplitude (a) and asymmetry ratio (b) of cVEMP in healthy individuals and individuals with Meniere's disease; star marks above the horizontal lines represent statistically significant comparisons.

ANOVA for ears with group as the between subject factor for CHAMP. The results revealed a significant main effect of ear [$F(1, 114) = 360.724$, $P < 0.05$] and group [$F(1, 114) = 537.135$, $P < 0.05$]. There was also a significant interaction between ear and group [$F(1, 114) = 420.630$, $P < 0.05$]. This necessitated separate ear-wise analysis for groups and group-wise analysis for ears using one-way repeated measures ANOVA and MANOVA, respectively. One-way repeated measures ANOVA for ears demonstrated a significant main effect of ear in the group of individuals with Meniere's disease [$F(1, 57) = 1180.603$, $P < 0.05$]; however there was no significant main effect of ears in healthy individuals group [$F(1, 57) = 0.859$, $P > 0.05$]. MANOVA was done for group-wise analysis which revealed a significant main effect of group for comparison between affected ears of individuals with Meniere's disease and matched ears of healthy subjects [$F(1, 114) = 889.161$, $P < 0.05$] but not for unaffected ears of individuals with Meniere's disease and matched ears of healthy subjects [$F(1, 114) = 2.263$, $P > 0.05$].

Thus, CHAMP revealed significantly smaller latency difference of wave V between click alone and click with 500 Hz high-pass masking noise in affected ears of individual with Meniere's disease than their unaffected ears. The latency difference in affected ear with Meniere's disease was also significantly smaller than the ears of healthy individuals. There was no difference in the latency difference between the ears of healthy individuals. Figure 4 shows the box-plots for latency difference between the stimulus conditions (click alone and click with high-pass masking noise with cut-off frequency at 500 Hz) in individuals with Meniere's disease as well as healthy individuals.

3.3. Comparison between CHAMP and cVEMP. Receiver operating characteristic curves were obtained to examine sensitivity and specificity of CHAMP and cVEMP in identifying Meniere's disease (shown in Figure 5). Areas under the curve for cVEMP and CHAMP were 0.863 and 1.0, respectively. Asymmetry ratio of ≥31% is considered for abnormality in cVEMP [21] and ≤0.3 ms difference in wave V latency between click alone and click + 500 Hz high-pass masking noise is as established for diagnosis of Meniere's disease using CHAMP [17, 43]. Using these values, the sensitivity and specificity were found to be 65.5% and 100%, respectively, for cVEMP whereas they are 93.1% and 100%, respectively, for CHAMP. Present study's data revealed optimum criterion points of ≥29% asymmetry ratio of cVEMP and ≤0.48 for CHAMP for identifying Meniere's disease. The use of these values produced 70.7% and 100% sensitivity and specificity, respectively, for cVEMP against 100% sensitivity and specificity for CHAMP.

4. Discussion

Cervical VEMP and CHAMP were administered on all individuals of both the groups of the study. These two potentials have been investigated separately in several previous studies; nonetheless reports on the same group of individuals to facilitate the comparison of their relative efficiency in identifying Meniere's disease remained elusive until the present study. The present study is the first step in this direction.

4.1. Cervical Vestibular Evoked Myogenic Potentials in Meniere's Disease. The present study compared the findings of cVEMP between Meniere's disease and healthy individuals. The results revealed significantly smaller peak-to-peak amplitude of cVEMP in the Meniere's group compared to the healthy controls. This is in agreement with those reported previously in this regard [15, 16]. This might be attributed to the changes observed at the vestibular periphery, especially the saccule. The histopathological studies in individuals with Meniere's disease have revealed severe hydrops frequently resulting in the distortion of the saccule or even rupture of

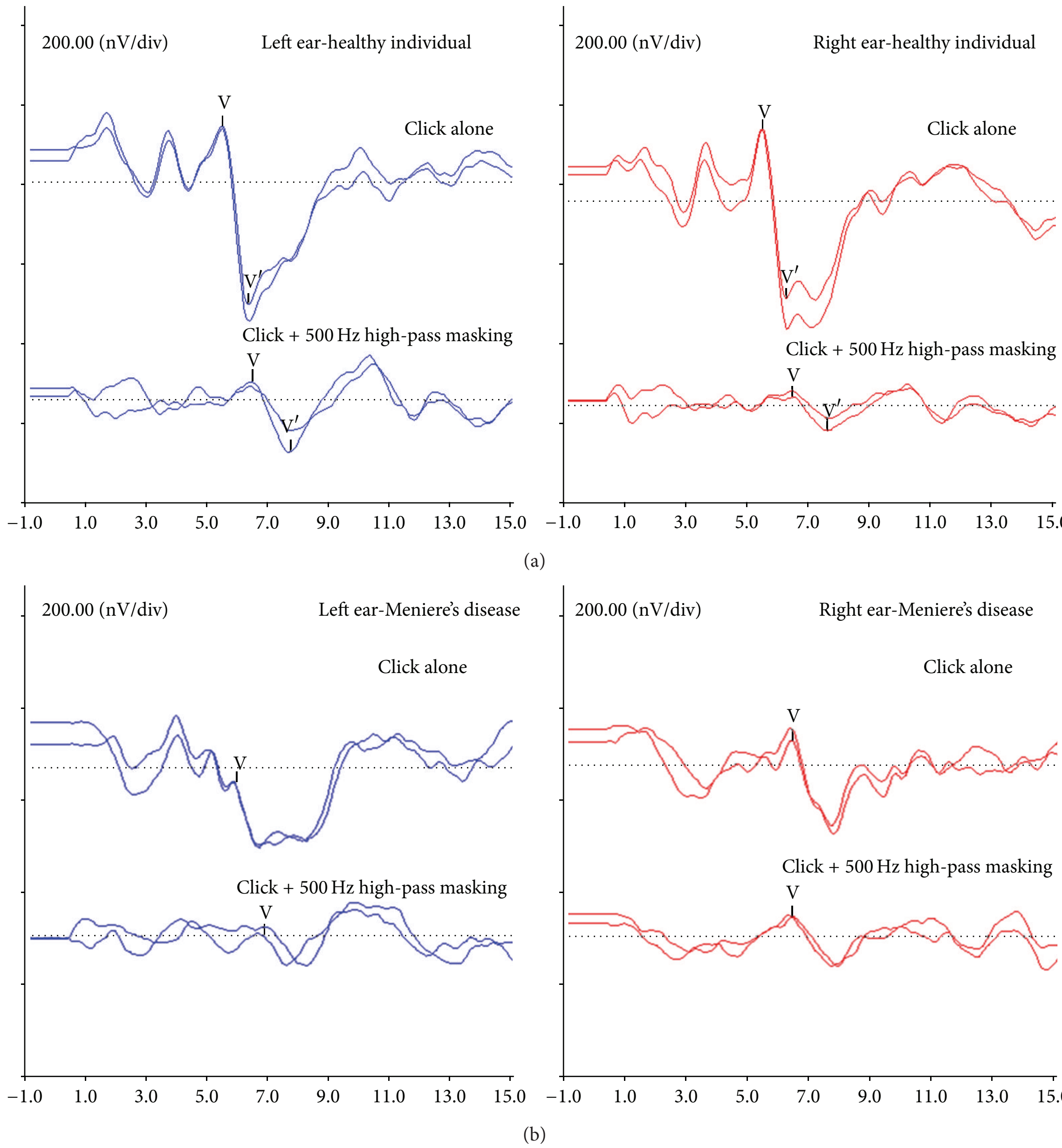

Figure 3: Representative waveforms of cochlear hydrops analysis masking procedure showing the responses for click alone and click with 500 Hz high-pass masking noise in an individual with Meniere's disease (bottom panels) and an age and gender matched healthy individual (top panels). In the individuals with Meniere's disease, right ear was the pathological ear.

the saccular membrane [44–46]. This distorted or ruptured saccular membrane is likely to affect the mechanical energy transfer that vibrates the saccular macula and stimulates the saccular hair cells. This is therefore likely to result in reduced amplitude on the affected side of individuals with Meniere's disease.

The results of the present study further showed significantly smaller peak-to-peak amplitude of cVEMP in the unaffected (asymptomatic) ears of individuals with Meniere's disease than the ears of healthy controls. Affected cVEMP responses in the asymptomatic ears of individuals were also reported previously [47–49]. The postmortem studies on the temporal bones of individuals with Meniere's disease demonstrated the presence of saccular hydrops in nearly 35% of the asymptomatic ears [50], which further substantiates the findings of the present study. This was called the "occult saccular hydrops" in the previous reports [50]. This means that there is a likelihood of binaural involvement in these individuals with a later onset of the symptoms in the unaffected ears. This data (findings of present study and those reported in literature in asymptomatic ears) correlates well with the data on binaural involvement in Meniere's disease which suggests binaural involvement in nearly 30% of the individuals with Meniere's disease. Therefore, a possibility of

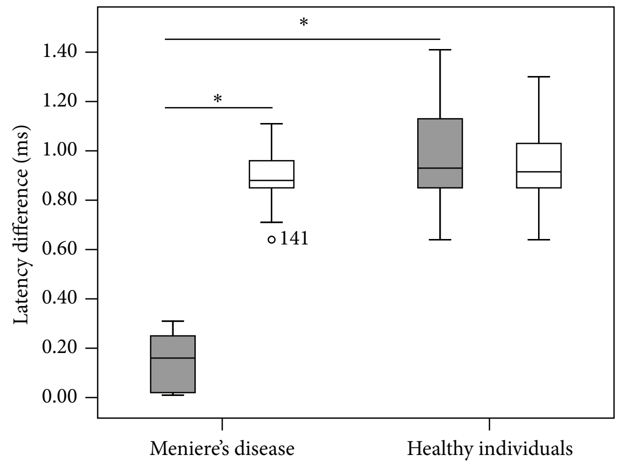

Figure 4: Box-plots for wave V latency difference between click alone and click + 500 Hz high-pass masking noise (CHAMP analysis) in healthy individuals and individuals with Meniere's disease. Grey shaded boxes represent affected ear of individuals with Meniere's disease and matched ear of healthy individuals. Unshaded boxes represent unaffected ears of individuals with Meniere's disease and matched ear of healthy individuals.

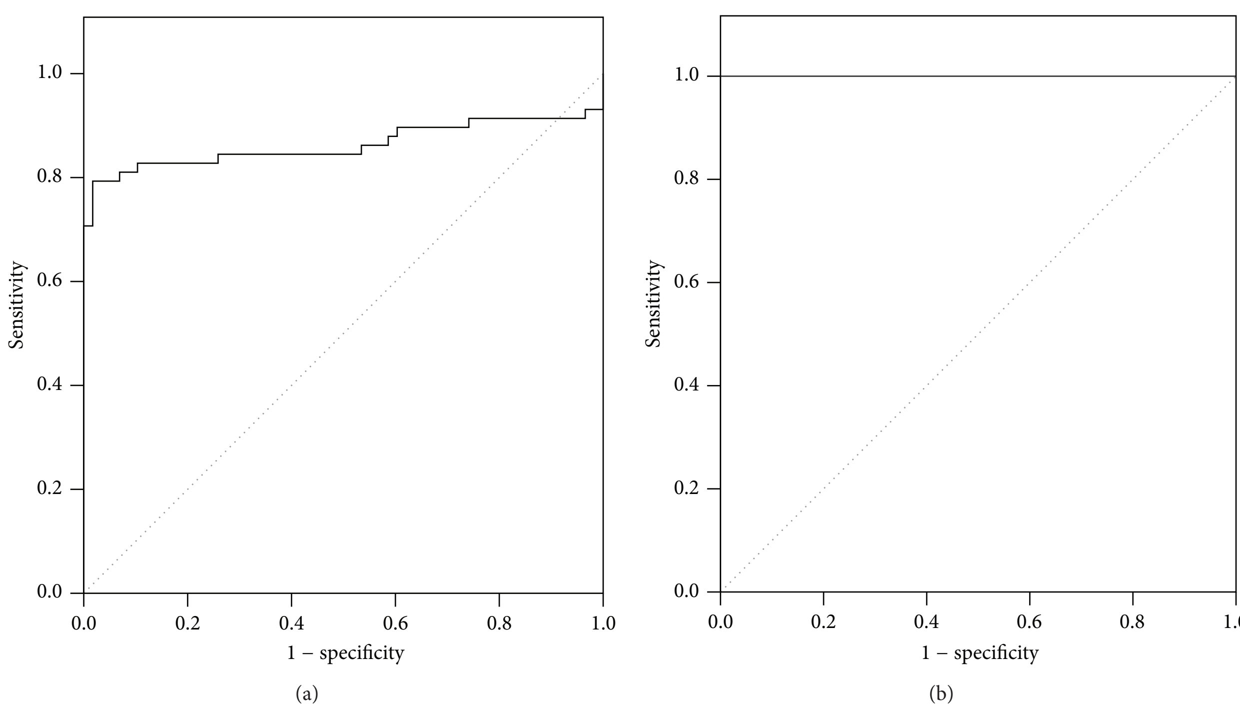

Figure 5: Receiver operating characteristic curves for sensitivity and specificity of cervical vestibular myogenic potential (a) and cochlear hydrops masking procedure (b) in identifying Meniere's disease.

binaural involvement with a later time of onset in the asymptomatic ears might explain the findings of the present study. However, this cannot be confirmed unless a longitudinal study on these individuals proves that occult saccular hydrops indeed was the reason for such a finding in the present study.

The results of comparison between the groups for asymmetry ratio of cVEMP revealed significantly higher value of asymmetry ratio in the group of individuals with Meniere's disease compared to the healthy individuals. This is in agreement with those reported previously [15, 16]. However, there is slight disagreement of these findings with Rauch et al. who reported no significant difference in asymmetry ratio between the group of Meniere's disease and healthy controls [25]. There was however an overall trend for greater asymmetry within Meniere's group compared to the controls in Rauch et al. [24]. Thus, the findings of the present study seem to be in agreement with those reported by Rauch et al. [25].

The finding of larger asymmetry ratio of cVEMP in Meniere's disease might be attributed to the unilateral nature of the pathology. The previous research reports have shown Meniere's disease to be mostly a unilateral pathology [2, 6]. cVEMP, being an ipsilateral response with almost no contribution from the contralateral side [18, 21, 30, 51, 52], would therefore be affected on one side but not on the other side, thereby producing larger asymmetry between the sides in Meniere's disease compared to the healthy controls.

The saccule has been reported to be the second most frequent site of endolymphatic hydrops among the inner ear structures, possibly due to its close proximity to the endolymphatic duct [53]. The mechanism for this increase in volume of endolymph is relatively unknown; however it is hypothesized that osmotic or hydrostatic changes along with the changes in permeability of ion channels are responsible for the symptoms in Meniere's disease. These abnormalities could cause an irregular flow of ions across the labyrinthine membrane stimulating vestibular sensory cells. In addition it is likely that the enlargement of the saccular duct pushes the outer hair cell stereocilia into a less sensitive position, which could result in the deficits of mechanoelectrical transduction [6, 54]. While it is not certain how hydrops would mechanically affect the saccular macula, it is possible that the organ could be affected by one or more of the above pathological mechanisms. Overall, it is relatively clear that the abnormal cVEMP responses suggest an alteration in the normal physiology of the saccule in patients with Meniere's disease [26].

4.2. CHAMP in Meniere's Disease. The results of CHAMP revealed significantly smaller difference in latency of wave V between click alone and click with 500 Hz high-pass masking pink noise in Meniere's disease compared to healthy controls. This is in agreement with some of the previous reports [17, 27, 55] but in not in agreement with others [32, 36]. The dissimilarity in findings might be attributed to the use of different population between the two sets of studies. The present study utilized only "definite Meniere's disease" as opposed to no such criteria chosen for participants' selection in these studies [32, 36].

Smaller difference between unmasked and masked condition in Meniere's disease compared to healthy controls could be attributed to reduced efficiency of the masker as a result of changes in the stiffness characteristics of the basilar membrane precipitated by Meniere's disease [17, 55]. One of the major characteristic changes induced by the presence of Meniere's disease is an increase in the travelling wave velocity [56]. The increased velocity of the travelling wave would affect the properties of the basilar membrane but cannot affect the tonotopic organization along the basilar membrane. The increased velocity of the travelling wave is more likely to impact the low frequencies as they are represented towards the apical end on the basilar membrane (further away from generation point). When ABR latencies are obtained by presenting clicks along with the high-pass masking noise in individuals with Meniere's disease, the altered motion mechanics of the basilar membrane limits the ability of low frequency noise to mask the activity in high frequency [56]. Hence in individuals with Meniere's disease, we can observe the phenomenon of undermasking in high-pass responses, whereas the undermasking phenomenon is not seen in normal individuals. This would in turn result in lesser latency difference between click alone and click with 500 Hz high-pass masking noise condition in ears with Meniere's disease than unaffected or normal ears.

4.3. Comparison between cVEMP and CHAMP in Identifying Meniere's Disease. The present study revealed higher sensitivity of CHAMP than cVEMP in identifying Meniere's disease. To the best of our knowledge, this is the first attempt at comparison between these two tests. The finding of better sensitivity of CHAMP than cVEMP in identifying Meniere's disease might be attributed to the extent of damage existing among different inner ear structures by the endolymphatic hydrops. The cochlea has been reported to be the most commonly involved site followed by the saccule and the utricle [53]. Since CHAMP is primarily a cochlea modulated auditory nerve response [17, 27, 55] and cVEMP a saccular response [18], lower sensitivity of cVEMP in comparison with CHAMP is justifiable. When a criterion of ≤ 0.48 for difference between click alone and click with 500 Hz high-pass masking noise was used for identification of Meniere's disease, the results revealed 100% sensitivity and specificity, similar to those reported previously, although for slightly different criteria [17, 55].

The above comparison of sensitivity and specificity of cVEMP and CHAMP appears to suggest that CHAMP is a better test for evaluating inner ear functioning in Meniere's disease. However, an inherent constraint in the recording of CHAMP arises from the use of only 60 dB nHL for click intensity. It is well known that the nHL thresholds obtained using the auditory brainstem response to clicks are 10 to 20 dB higher than the behavioral auditory thresholds in HL [47, 57]. This would mean that for losses exceeding moderate degree, an auditory brainstem response to 60 dB nHL clicks would be absent since ABR thresholds for clicks have been reported to be 10–20 dB higher than the actual behavioral threshold. Thus CHAMP would appear to be useful only up to a moderate degree of hearing loss. On the contrary, the degree of sensorineural hearing loss does not impact the VEMP responses in anyway [47]. Therefore, it would be useful for evaluating patients of Meniere's disease with any degree of hearing loss. In the present study, all the participants had moderate or lesser degrees of hearing losses (although it was not planned to select participants with only such degrees of hearing losses), and hence the results show a higher sensitivity for CHAMP than cVEMP. This might not be the case, if the degree of hearing loss in some subjects exceeded moderate degree.

The results of the present study demonstrated significantly impaired cVEMP responses in the unaffected ears of individuals with Meniere's disease. However, such an occurrence was not observed for CHAMP which revealed no significant difference between the unaffected ears of Meniere's disease group and the ears of healthy controls. The postmortem studies on the temporal bones of individuals with Meniere's disease have previously revealed saccular involvement in the largest proportion of individuals followed by cochlea, utricle, and the semicircular canals [45]. This probably indicates that a saccular involvement without cochlear function compromise could be an early sign of onset of Meniere's disease in the asymptomatic ears. Since cVEMP is mainly a saccule mediated response while CHAMP is a cochlear mediated response, the lack of significantly altered CHAMP results in presence of significantly altered cVEMP responses in the asymptomatic ears could be understood. This further indicates that cVEMP could be a better tool to identify presymptomatic saccular hydrops and possibly predict the onset of binaural involvement of Meniere's disease in those who already have a unilateral pathology.

5. Conclusion

Both cVEMP and CHAMP showed statistically significant differences between individuals with Meniere's disease and healthy individuals and therefore both the tests are sensitive in identifying Meniere's disease induced changes in the inner ear. The receiver operating curves revealed 100% sensitivity and specificity for CHAMP as against 70.7% and 100% for cVEMP which appears to indicate that CHAMP is better test for evaluation of Meniere's disease than cVEMP. However, CHAMP can only be recorded for losses not exceeding moderate degree, which limits its use to identifying Meniere's disease with lesser degree of hearing losses only. No such limitations are imposed by the degree of hearing loss on cVEMP. Thus CHAMP could be the test of choice for hearing losses not exceeding moderate degree and cVEMP could be used for all degrees of hearing losses, although with slight constraint on sensitivity. Further, cVEMP could also prove useful in identifying the occult Meniere's disease in the asymptomatic ears of individuals with unilateral Meniere's disease.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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