Vestibular evoked myogenic potentials are a group of somotor responses that arise in the vestibular part of the labyrinth and can be recorded from several muscles of the body. When recorded from the flexed inferior oblique muscle, they are called as oVEMP (Todd et al., 2003; Rosengren et al., 2005). This response from the inferior oblique muscle is a biphasic response with a negativity at about 10 ms (called n10 or n1) and a positivity at about 15 ms (known as p15 or p1) after the stimulus onset. The oVEMP are well accepted to be robust when recorded using electrodes beneath the contralateral eye and therefore thought to represent the response from the crossed utriculo-ocular reflex arch (Manzari et al., 2010; Curthoys et al., 2012).

Several histopathological investigations have shown presence of utricle and/or utriculo-ocular pathway dysfunction in vestibular pathologies like Meniere’s disease and BPPV (Okuno & Sando, 1987; Parnes & McClure, 1992; von Brevern et al., 2006). Nonetheless, the feasibility of histopathological examination for diagnosis of a vestibular pathology in living human beings could only be through invasive procedures. This paved a path for exploring techniques that could prove useful in evaluating utricular or utriculo-ocular pathway functioning without being invasive.

The initial reports on tests such as sinusoidal off-vertical axis rotation, subjective visual vertical and head-tilting stabilometry using rotatory chair test appeared to be potentially useful for the assessment of utricular or utriculo-ocular pathway function in individuals with utricular pathologies (Hess & Diefinger, 1990; Sugita-Kitajima et al., 2007; Faralli et al., 2009; Kumagami et al., 2009). However, some of the reports
demonstrated that these results were not specific to any pathology or site of lesion by showing positive results in cerebral hemisphere lesions (Yelnik et al., 2002; Bonan et al., 2006; Sugita-Kitajima et al., 2007). Additionally, the responses on these tests are not ear specific and are many times insensitive to the common vestibular lesions which are unilateral in origin (Wuyts et al., 2001, 2003).

The ocular VEMP was not only sensitive to unilateral vestibular pathologies and produced ear specific responses, but also useful in assessment of utricular involvement in several vestibular pathologies like Meniere’s disease (Taylor et al., 2011; Zuniga et al., 2012), vestibular neuritis/ labyrinthitis (Moon et al., 2012a, b), BPPV (Nakahara et al., 2013; Seo et al., 2013; Singh & Barman, 2014), multiple sclerosis (Gabelic et al., 2013) and ANSD (Sinha et al., 2013). Additionally, oVEMP lends itself to better patient tolerance and is less expensive as it can be administered using most of the commercially available auditory evoked potential systems. However, the use of latency, absolute amplitude, threshold and inter-aural asymmetry ratio of oVEMP continued to provide findings that were not specific to a particular disorder. Therefore, there was a need for more specific response parameter of oVEMP so that it could differentiate not only pathologies from healthy individuals but also be able to distinguish between the pathologies. This possibly has drawn attention of the researchers about the usefulness of the frequency tuning property of oVEMP as a parameter to diagnose utriculopathies.

The initial results of frequency tuning showed potential in the diagnosis of Meniere’s disease by virtue of demonstrating shift in frequency tuning from 500 Hz in healthy individuals to 1000 Hz in Meniere’s disease (Sandhu et al., 2012; Winters et al., 2012; Jerin et al., 2014). However, these studies either investigated the frequency tuning property using a very limited small sample size or ignored the use of certain mid-octave
frequencies. Further, most of them did not control for the effects of age, a factor that was later shown to affect the frequency tuning of oVEMP even in healthy individuals (Piker et al., 2013). These studies also did not investigate whether the shift in frequency tuning was an exclusive feature of Meniere’s disease or other vestibular pathologies could possibly also show a similar shift in frequency tuning. Lastly, there was no consensus regarding the frequency tuning of oVEMP even in healthy individuals with some showing frequency tuning at 500 Hz (Sandhu et al., 2012; Winters et al., 2012; Singh & Barman, 2013, 2014) whereas others found it to be at 1000 Hz (Lewis et al., 2010; Taylor et al., 2012).

The above mentioned factors unveil the need to investigate the frequency tuning of oVEMP in healthy individuals and examine whether it differed from some of the well known vestibular disorders like Meniere’s disease, BPPV and ANSD. Also, there was a need to investigate the difference in frequency tuning properties, if any, between these vestibular pathologies. Therefore, the aim of the present study was to characterize the frequency tuning of oVEMP in healthy individuals and those with Meniere’s disease, BPPV and ANSD. Additionally the present study also aimed to investigate the existence of a difference, if any, in frequency tuning properties between these vestibular disorders.

For the fulfilment of these aims, the oVEMP responses were recorded from individuals with unilateral definite Meniere’s disease (N = 36, 22 males & 14 females, age range = 15-50 years, mean age = 36.1 years, standard deviation = 9.1, median age = 36.5 years), unilateral BPPV (N = 36, 17 males & 19 females, age range = 15-50 years, mean age = 40.1 years, standard deviation = 10.0, median age = 41.5 years) and bilateral ANSD (N = 36, 18 males & 18 females, age range = 15-50 years, mean age = 22.9 years, standard deviation = 7.6, median age = 20.5 years). The individuals with definite Meniere’s disease were selected based on the fulfilment of the criteria lead out by the AAO-HNS (1995). The
individuals with BPPV were chosen based on the criteria proposed for diagnosis of BPPV by AAO-HNS (Bhattacharya et al., 2008). The individuals with ANSD were selected based on the findings of absent auditory brainstem responses, acoustic reflexes and present oto-acoustic emissions and the diagnosis was further confirmed by an experienced neurologist. The oVEMP responses were also obtained from 113 healthy individuals (57 males & 56 females, age range = 15-50 years, mean age = 32.4 years, standard deviation = 11.1, median age = 31.0 years), who had normal auditory and vestibular functioning. Out of the 113 healthy individuals, only 36 each were used as age- and gender-matched controls for the three clinical groups.

Ocular VEMP were obtained from the electrodes placed beneath the contralateral eye (with respect to acoustic stimulus) and forehead, with non-inverting electrode 1 cm below the eye, inverting 2 cm below the non-inverting electrode and ground on the forehead. During the recording, the participants were instructed to maintain eye gaze in the supero-medial direction at an elevation of 30°-35°. The stimuli used were alternating polarity tone-bursts at octave and mid-octave frequencies from 250 Hz to 4000 Hz. The order of their presentation was changed in a pseudorandom fashion to avoid order effect. The testing was started at 125 dB peSPL and the intensity was reduced using 10 dB step-size until the threshold was achieved. The responses were filtered using 1-1000 Hz band-pass filter and multiplied by a factor of 30000. An inter-frequency rest time of 1 minute or as per participants’ request was provided to avoid fatigue, eye watering or irritation.

The finding of non-normally distributed data at most of the frequencies (Kolmogrov-Smirnov test) resulted in the use of non-parametric statistical methods for within and between groups comparisons. A Chronbach alpha test was used to investigate the test-retest reliability of peak-to-peak amplitude, oVEMP thresholds and frequency tuning. The
McNEmar tests was used for within group comparison of response rates between ears and between frequencies. The Equality of tests for proportion was used for between groups comparison of response rates and also for proportion of ears with frequency tuning at a particular frequency. The comparisons of data obtained across frequencies required the use of Friedman’s test for overall effects and this was followed by Wilcoxon test for pair-wise comparison between frequencies, whenever necessary. This was done for peak-to-peak amplitude and oVEMP threshold. The between group comparisons necessitated the use of Mann-Whitney U test for pair-wise comparison of peak-to-peak amplitude and oVEMP threshold. The Receiver operating characteristics (ROC) analysis was used in order to obtain the ROC curves, the criterion point, sensitivity as well as specificity of frequency tuning measure of oVEMP in identifying Meniere’s disease. The results for within and between groups comparisons as well as test-retest reliability are discussed below for each of the groups of the present study:

1. **Healthy individuals:** oVEMP were recorded across the frequencies from both ears of 113 healthy individuals. Separate ear-wise and frequency-wise analysis was done for response rates, peak-to-peak amplitude and oVEMP threshold. Frequency tuning was also analyzed separately for the right and left ears. Further, test-retest reliability was examined on randomly selected 10 individuals from this group. The results of this group are discussed below:

A. **Within group comparisons:** The across frequency comparison revealed significantly higher response rates at 500 Hz, 750 Hz and 1000 Hz than the other frequencies. Further, the peak-to-peak amplitudes were significantly larger and thresholds were significantly better (lower) at 500 Hz and 750 Hz compared to all the other frequencies. The frequency tuning was observed at 500 Hz or 750 Hz in almost 99% of the ears of healthy individuals. The finding of higher response rate, larger peak-to-peak amplitude, better thresholds and
presence of frequency tuning at 500 Hz or 750 Hz in healthy individuals could be attributed to the resonance properties of utricle that appears to enhance the frequency response to these low-to-mid frequencies (Todd et al., 2000, 2009b). Further, the responses to 4000 Hz were absent in 92.92% (210 out of the 226) ears which suggests that 4000 Hz should not be used for clinical recording of oVEMP.

B. Test-retest reliability: Peak-to-peak amplitude, oVEMP threshold as well as frequency tuning demonstrated excellent test-retest reliability across the frequencies, except peak-to-peak amplitude at 4000 Hz. The previous studies obtained test-retest reliability of only peak-to-peak amplitude and only at 500 Hz; nonetheless they reported moderate to excellent test-retest reliability (Nguyen et al., 2010; Singh, et al., 2011). Obtaining lower value of the Chronbach ‘α’ coefficient at 4000 Hz could be attributed to the presence of response in only 3 ears (out of 20) and therefore even slight variability could have significantly impacted the results of test-retest reliability.

2. Meniere’s disease group: The Meniere’s disease group consisted of 36 participants with unilateral definite Meniere’s disease. In order to compare the findings of oVEMP in them, 36 age- and gender-matched healthy individuals were used as control group. The results are discussed below:

A. Within group comparisons: The across-frequency comparison in the affected ears of individuals with Meniere’s disease revealed higher response rates, larger peak-to-peak amplitudes, and better thresholds at 1000 Hz than the other frequencies. These findings could be attributed to changes in the mechanical properties that are induced by the accumulation of excessive amounts of endolymph which was shown to produce the distension of the utricular membrane (Okuno & Sando, 1987; Young et al., 2002; Merchant et al., 2005; Morita et al., 2009). This is likely to result in an increase in the
stiffness and a consequent increase in the resonance frequency of the utricle in the affected ears of individuals with Meniere’s disease.

The inter-ear comparisons in the Meniere’s disease group revealed lower response rates, shorter peak-to-peak amplitude and poorer (elevated) thresholds in the affected ears than the unaffected ears, although statistically significant difference was observed only at some of the frequencies. Nonetheless, this finding could be attributed to the reduction in response caused by the hydrostatic changes caused by the mechanical deformation of the otolith organs (Tonndorf, 1983; Brown, Chihara, & Wang, 2013) and the ionic disturbances within the labyrinth on the affected side (Vosteen & Morgenstern, 1986).

**B. Between groups comparisons:** The between groups comparisons revealed lower response rates, smaller peak-to-peak amplitudes and poorer thresholds in the affected ears of Meniere’s disease group than the matched ears of healthy controls. These findings could be attributed to the reduction in response caused by the hydrostatic changes caused by the mechanical deformation of the otolith organs and the ionic disturbances within the labyrinth on the affected side (Tonndorf, 1983; Vosteen & Morgenstern, 1986; Brown et al., 2013), as mentioned above.

Further, the unaffected ears of individuals with Meniere’s disease demonstrated poorer thresholds and significantly higher proportion of ears with frequency tuning at 1000 Hz than the matched ears of the healthy controls. These findings could be attributed to the ‘occult’ or ‘latent’ Meniere’s disease in the unaffected ears which has been described in several previous investigations using other kinds of tests like cVEMP (Ribeiro et al., 2005; Linn et al., 2006; Fouly et al., 2012), electrocochleography (Visu & Singh, 2012) and oto-acoustic emissions (Magliulo et al., 2004).

The analysis using the ROC curves in the present study revealed an optimum criterion point of ≥ 875 Hz for detecting Meniere’s disease. Using this criterion point, the
sensitivity of 68% and specificity of 100% was found for detecting Meniere’s disease. These values appear to be encouraging enough to recommend the clinical use of this measure to identify Meniere’s disease.

3. **BPPV group:** The BPPV group consisted of 36 participants with unilateral BPPV. Their oVEMP results were compared between their two ears and also against 36 age- and gender-matched healthy controls. The findings are delineated below:

**A. Within group comparisons:** Significantly higher response rates, larger peak-to-peak amplitudes and better (lower) thresholds were obtained at 750 Hz than the other frequencies in both the ears of the BPPV group. The frequency tuning was also observed at 750 Hz or 500 Hz in majority of the ears in the BPPV group. This could be attributed to the resonance frequency of the utricle around these frequencies, as demonstrated previously by Todd et al (2000, 2009). Thus it suggests that pathological condition in individuals with BPPV is less likely to alter the resonance properties of the utricle significantly.

The within group comparison in the BPPV group revealed significantly smaller peak-to-peak amplitude in the affected ears than the unaffected ears at each of the frequencies till 1500 Hz. This could be due to the utricular pathology in the affected ears, the evidence for which was shown by histopathological studies (Parnes & McClure, 1992; Buckingham, 1999; von Brevern et al., 2006) as well as other tests meant for the measurement of utricular function (Markham et al., 1987; Takeda et al., 1997; Sugita-Kitajima et al., 2007; Hong et al., 2008; Faralli et al., 2009).

**B. Between groups comparisons:** The affected ears of the BPPV group demonstrated significantly lower response rates, smaller peak-to-peak amplitudes and poorer thresholds than the matched ears of healthy controls; although significant difference was not found at some of the frequencies. These findings could be attributed to the presence of utricular
impairment in the affected ears of individuals with BPPV (Parnes & McClure 1992; Markham et al., 1987; Takeda et al., 1997; Buckingham, 1999; von Brevern et al., 2006; Sugita-Kitajima et al., 2007; Hong et al., 2008; Faralli et al., 2009).

Nearly 60% of both the ears of BPPV group showed frequency tuning at 750 Hz whereas almost 40% showed frequency tuning at 500 Hz. There was no difference in the proportion of ears with frequency at any frequency between the BPPV group and the age- and gender-matched healthy controls. The existence of frequency tuning at 500 Hz or 750 Hz in almost all the clinical and the control ears could be explained on the basis of the second order mass-spring model put-forth by Todd et al (2000b). This further shows that slight changes in the mechanical properties of the utricle that might have occurred due to the loss of otoconia from the utricular macula was not sufficient to cause a shift in the frequency tuning.

4. **ANSD group:** The ANSD group consisted of 36 participants with bilateral ANSD. The findings of oVEMP in this group were compared against 36 age- and gender-matched healthy controls in terms of response rate, peak-to-peak amplitude, oVEMP threshold and frequency tuning. The results in this group are discussed below:

A. **Within group comparisons:** The ANSD group revealed presence of oVEMP in only 11 (30.55 %) right ears and 8 (22.22%) left ears at least at one frequency and only up to 1000 Hz. The absence of responses at all the frequencies in a large majority of the individuals with ANSD could be an indicator of pathology in the utriculo-ocular reflex pathway. The anatomical alterations such as reduced neuronal population between the utricle and the scarpà’s ganglion, irregular beaded appearance of the nerve fibres, fragmentation of the myelin layer with gaps as large as the diameter of the nerve fibers and/or a completely distorted vestibular nerve was found in the individuals with ANSD (Starr et al., 2003). This supports the finding of existence of vestibular pathology in majority of these
individuals which was also demonstrated by the results of tests like electronystagmography (Fuzikawa & Starr, 2000; Sheykholeslami et al., 2005), videonystagmography (Ismail et al., 2014) and cVEMP (Wu et al., 2004; Sheykholeslami et al., 2005; Kumar et al., 2007; Akdogan et al., 2008; Sazgar et al., 2010; Ismail et al., 2014).

The highest response rates, largest peak-to-peak amplitudes and best thresholds were observed at 500 Hz and 750 Hz which were significantly higher than that at 250 Hz and 1000 Hz in individuals with ANSD. Further, frequency tuning was observed at 500 Hz in nearly 60% of the individuals with ANSD whereas the remaining individuals demonstrated frequency tuning at 750 Hz. This suggests that the vestibular pathology in individuals with ANSD is more of a neural origin than utricular since Todd et al (2009b) had reported that major contribution to frequency tuning of oVEMP arises out of the resonance of the utricle.

B. Between groups comparisons: The between groups comparisons revealed significantly lower response rates, smaller peak-to-peak amplitudes and poorer thresholds of oVEMP in individuals with ANSD than the age- and gender-matched healthy controls. This could be attributed to the dys-synchronous firing of neural elements that were shown to reduce the amplitude of the compound action potential that is recorded from the surface electrodes (Starr et al., 2001). Since the studies on individuals with ANSD have shown affected neural reflexes involving the superior vestibular nerve (Fuzikawa & Star, 2000; Sheykholeslami et al., 2005; Ismail et al., 2014), these findings of oVEMP in ANSD thus could be explained.

Further the results revealed no significant difference in the proportion of ears with frequency tuning at 500 Hz or 750 Hz between the groups. The existence of frequency tuning at 500 Hz or 750 Hz in almost all the clinical and the control ears could be explained on the basis of the second order mass-spring model put-forth by Todd et al
Further, the similarity in the findings of the frequency tuning between the individuals with ANSD and the healthy controls is a testimony to the fact that the contribution to frequency tuning mainly arises from the utricle and that there is minimal, if any, contribution of neural system in frequency tuning of oVEMP. A similar view-point about frequency tuning of oVEMP was proposed by Todd et al. (2009b).

5. **Comparison of frequency tuning of oVEMP among the pathological groups:**

The between groups comparison revealed significantly higher proportion of ears with frequency tuning at 1000 Hz and lower at 500 Hz in the affected ears of individuals with Meniere’s disease compared to the affected ears with BPPV and the ears with ANSD. There was no significant difference in the proportion of ears with frequency tuning at any frequency between the BPPV group and the ANSD group.

In the Meniere’s ears, the excessive accumulation of the endolymph within the utricle has been shown to cause distention of the utricular membrane (Okuno & Sando, 1987; Young et al., 2002; Merchant et al., 2005; Morita et al., 2009) which causes increase in stiffness and thereby an increase in the resonance frequency (Vanhuyse et al., 1975; Popelka & Hunter, 2013). In the ANSD ears, there is no known change in the mechanics within the utricle rather there could be a pathology involving the hair cells, the junction between the hair cells and the neurons and/or the nerve itself (Harrison, 1998; Gibson, 2002; Amatuzzi et al., 2011; Nachman, 2012). The loss of otoconia particles from the utricle in the affected ears of BPPV has been well documented (Parnes & McClure, 1992; Buckingham, 1999; von Brevern et al., 2006) which should theoretically alter the mass of the macula and thereby the resonant frequency. Nonetheless, the results of the present study suggests that the reduction in mass caused by the loss of otoconia particles in the BPPV ears is not large enough to sufficiently shift the peak of the frequency tuning curve to an expected higher frequency. Thus the results of the current study suggest that
frequency tuning could differentiate the affected ears with Meniere’s disease from the affected ears with BPPV and those with ANSD.

6. **Comparison of frequency tuning of oVEMP among the comparison groups used for the three clinical groups**: The control group used for BPPV group demonstrated higher proportion of ears with frequency tuning at 750 Hz than 500 Hz. However, the control groups used for Meniere’s disease and ANSD revealed larger proportion of ears with frequency tuning at 500 Hz than at 750 Hz. Although this difference was statistically not significant \( p > 0.05; \) Equality of test for proportions), this finding could be explained by the effects of age. Piker et al (2013) demonstrated higher incidence of frequency tuning at 500 Hz in the young adults group (20 to 39 years) whereas the proportion of individuals demonstrating frequency tuning at 750 Hz increased and at 500 Hz decreased in the middle aged group (40 to 59 years) and older adults (above 60 years). The mean age of the control group for BPPV was slightly higher and this group consisted of more number of individuals above 40 years of age than the other two control groups in the present study. This could have therefore caused more number of individuals with frequency tuning at 750 Hz than 500 Hz in the control group for BPPV than the other two control groups.

Therefore to conclude, the findings of present study demonstrated very low response rate and fair/moderate test-retest reliability of response amplitude at 4000 Hz and therefore its use for clinical recording of oVEMP would be ill advised. Higher response rates, larger amplitudes and better thresholds were observed at 500 Hz, 750 Hz, 1000 Hz and 1500 Hz and therefore these frequencies are recommended for clinical use for finding frequency tuning of oVEMP. Further, the findings of the present study implicate that the shift in the peak of frequency tuning to a higher frequency (1000 Hz or more) is a property that is unique to Meniere’s disease. It can therefore be used clinically not only to identify the presence of a utricular pathology in an individual with Meniere’s disease but also prove
helpful in the differential diagnosis of Meniere’s disease from other vestibulopathies involving the utricle and/or the utriculo-ocular pathway.

**Implications of the study**

The findings of the present study showed excellent test-retest reliability of amplitude, threshold and frequency tuning of oVEMP. Therefore, oVEMP can be reliably recorded from nearly all the healthy individuals. High test-retest reliability also indicates that the test can be used in clinical population to identify abnormalities of the vestibulo-ocular pathway.

The results of the present study showed that oVEMP could be recorded more often for 750 Hz and 1000 Hz than the conventionally used 500 Hz. Therefore future clinical recordings of oVEMP could benefit from using 750 Hz or 1000 Hz instead of 500 Hz as the use of these frequencies will enhance the chances of obtaining an oVEMP response in almost 100% of the normal population.

The use of 4000 Hz for obtaining oVEMP yielded responses in very few individuals (about 7% ears), even in the healthy individuals group. Therefore, this frequency need not be used for either research or clinical purposes.

The results of the present study showed that frequency tuning was different (higher proportion of individuals showed tuning at 750 Hz) in the control group used for BPPV group than those used for Meniere’s disease and ANSD groups. This suggests that age-matched control groups are necessary when frequency tuning is being used to study the effectiveness of using frequency tuning for identifying abnormality.

Considering that oVEMP is a utricle generated response and it can be reliably recorded, it would fill an important void in the test battery as there are not many reliable tests available for evaluating the utricular function. The presence of oVEMP in nearly all
the healthy individuals seems to suggest that it can be used to differentiate an abnormal utricular response from a normal one.

The outcome of the current study showed that the frequency tuning of oVEMP was at 500 Hz or 750 Hz in the healthy individuals as against 1000 Hz or higher frequencies in Meniere’s disease. Therefore, frequency tuning of oVEMP can be used to identify the presence of utricular pathology in the ears affected with Meniere’s disease.

The present study also revealed the presence of frequency tuning at 1000 Hz in the asymptomatic ears of some of the individuals with Meniere’s disease. The finding of shift in frequency tuning in some of the asymptomatic ears of individuals with unilateral Meniere’s disease possibly indicates presence of latent endolymphatic hydrops in the asymptomatic ears of these individuals. Therefore, frequency tuning of oVEMP might be potentially useful in predicting a bilateral involvement in future.

Frequency tuning of oVEMP was found to be at 500 Hz or 750 Hz in the ears with BPPV and ANSD whereas it was at 1000 Hz or higher frequencies in ears with Meniere’s disease. Therefore, the finding of frequency tuning at 1000 Hz or higher frequencies is unique to Meniere’s disease and this could therefore be used for differential diagnosis of Meniere’s disease from other vestibular pathologies.

**The study was limited to**

The test-reliability was measured only for the healthy individuals and not for the clinical groups. The measurement of test-retest reliability in the pathological groups could have yielded better insight into the changes that might be encountered across test sessions even in various pathologies. This was not done in the current study as this would require the patient to be devoid of any management options for two weeks or more which could be unethical.
The present study did not account for the effect of middle ear transfer function on the frequency tuning of oVEMP. However it is less likely that the results were affected significantly by the middle ear transfer function as Piker et al (2013) showed that the best frequency (peak of the frequency tuning curve) of oVEMP was independent of the middle ear transfer function. Therefore, this was not considered a concern in the present study.

The present study used only two other pathologies (BPPV & ANSD) for evaluating the efficiency of frequency tuning property of oVEMP in differential diagnosis of Meniere’s disease from other vestibular pathologies. Future studies could be done to evaluate the efficacy of frequency tuning of oVEMP in differentiating Meniere’s disease from other vestibular pathologies that could not be accommodated in the present study.

The use of 10 dB step-size to arrive at oVEMP threshold could obscure the finer differences in the thresholds between the frequencies which could affect the frequency tuning curves and their interpretations. However, the use of smaller step-sizes would have required more number of recordings thereby causing fatigue through the act of maintaining an upward gaze for long. Further, it would have also exposed the ears to loud sounds for much longer duration, which appears to be a growing concern after a recent publication reported of deleterious impact of sound levels used for recording VEMP (Krause et al., 2013). Therefore, smaller step-sizes were not included in the present study.

The study was limited in some ways due to the above mentioned reasons. Although, the reasons for not having taken care of the above mentioned factors are clear, the future studies could take them in to account when studying the frequency tuning of oVEMP.