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Masseter vestibular-evoked myogenic potentials at different tone burst frequencies in healthy individuals

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Abstract

Background Masseter vestibular-evoked myogenic potentials (mVEMP) are vestibular-dependent inhibitory reflex recorded using acoustic stimulus. mVEMP can assess important brainstem regions. mVEMP abnormalities have been reported in patients with multiple sclerosis, Parkinson's disease, and idiopathic random eye movement disorder. The objective of the study was to record mVEMP using tone-burst stimulus at different frequencies in young healthy individuals.

Method The study used normative study design. Thirty-two participants, aged 18–28 years with normal hearing and balance function, were recruited for the study. Simple random sampling was used for selection of participants.

Data collection and analysis mVEMP was recorded for all the individuals at 500 Hz,750 Hz,1000 Hz, 2000 Hz, and 4000 Hz tone burst stimuli. The p11 and n21 peaks were identified. The latency of the p11 and n21 peaks and the rectified amplitude of the p11-n21 peak complex were measured for all the participants. Wilcoxson signed-rank test was used for statistical anlysis.

Results The study found a 100% response rate and higher amplitude for 500 Hz and 750 Hz tone burst stimuli. However, Wilcoxson signed-rank test with Bonferroni correction showed no significant difference in amplitude ($p = 0.92$) between 500 and 750 Hz.

Conclusion The study recommends 500 Hz/750 Hz tone burst stimuli as an optimal frequency for recording mVEMP in young, healthy individuals. However, seeing the frequency-tuning characteristics of mVEMP in other peripheral vestibular pathologies would be interesting.

Keywords mVEMP, Frequency tuning, Stimulus frequency, Vestibulomassetric reflex

Background

Masseter vestibular-evoked myogenic potentials (mVEMP) are vestibular-dependent inhibitory reflexes recorded using an acoustic stimulus. mVEMP assesses the vestibulotrigeminal reflex pathway, which helps to maintain the human jaw against gravity. It was first recorded in humans using transmastoid electrical stimulation [1] and over time with an acoustic stimulus [2]. In addition to vestibular system integrity, mVEMP also assesses the brainstem structures in patients with dizziness.

mVEMP is sensitive in monitoring the pathophysiologic changes in the brainstem in individuals with various pathologies. In patients with Parkinson's disease, the frequency of abnormality of VEMPs has been reported to be 41.7%, 45.8%, and 66.7% for cervical, ocular, and masseter VEMPs, respectively [3]. De Natale et al. [4] reported a significant reduction in amplitude of the masseter and ocular VEMPs in late Parkinson's disease. The combined use of VEMPs and auditory-evoked potentials

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shows higher sensitivity in detecting brainstem lesions in individuals with multiple sclerosis than MRI or clinical testing [5]. Magnano et al. [6] reported brainstem abnormality in 82.2% of patients with multiple sclerosis using mVEMPs, 84.4% using brainstem auditory-evoked potentials, 77.8% using MRI, and 40% using clinical examination at baseline. A recent study on multiple sclerosis also found mVEMP to be superior in detecting brainstem lesions than cervical and ocular VEMP in patients with multiple sclerosis [7]. Studies have also reported prolonged p11 latency and reduced amplitude in mVEMP for isolated random eye movement sleep behavior disorder than controls [8].

In general, the mass and stiffness work in opposition, whereas resonance occurs when the mass and stiffness of the system become equal. Using different tone burst frequencies to elicit VEMPs infers about the optimal resonant frequency of the vestibular system. Cervical cVEMP and ocular oVEMP have been studied in detail concerning different acoustic stimulus types [9–13]. Most of the research equivocally showed tone burst stimuli being better stimuli in eliciting the VEMP responses than clicks and chirp stimuli [9–13]. The study's results on frequency tuning of VEMPs have revealed better amplitude of VEMP with 500 Hz and 750 Hz tone burst than higher frequencies [14–17]. Murofushi et al. [18] were the first reserachers to find out the frequency tuning of the vestibular-evoked myogenic potentials.

There are two components of masseter VEMPs, one is acoustic in nature, and other one is vestibular in nature. The first component is p11-n15 having a higher threshold from the vestibular system, and the second component is p16-n21 having a relatively lower threshold from the cochlear system. The findings have been confirmed in patients with cochlear and vestibular lesion, wherein p11/n15 wave was present only in patients with cochlear lesion, and p16/n21 wave was present in vestibular lesion [19]. On the other hand, the cVEMP and oVEMP have been reported to be pure vestibular in nature. Hence, it would be interesting to understand the mVEMP tuning mechanism in normal hearing individuals. The study results can tell whether the mVEMP tuning is again dependent upon the vestibular mechanism, or it also is influenced by the acoustic mechanisms.

In some vestibular disorders, the otolith organ's mass and stiffness properties are considerably altered, resulting in altered VEMP characteristics. In such instances, frequency-specific VEMP helps in detecting the pathology. Researchers studied frequency tuning of VEMPs using tone burst stimuli such as 250 Hz, 500 Hz,1000 Hz, and 2000 Hz for both controls and semicircular canal dehiscent syndrome (SCD) [20]. Researchers reported 2–3 times larger cVEMP amplitude and 10–30 times larger amplitude for oVEMP in individuals with semicircular canal dehiscent syndrome than controls in SCD. It has also been reported that the 4-kHz stone burst elicits oVEMP responses in 100% of the population with SCD [21]. The sensitivity and specificity of oVEMP at 4 KHZ has been reported to be 83% and 93% respectively in individuals with SCD [22]. In patients with Meniere's disease,1000-Hz tone burst stimuli elicit higher amplitude and low threshold of VEMPs than healthy controls [23–25].

Evidence shows that the masseter and cervical VEMP share the same afferent pathway [2]. Other similarities between cervical VEMP and mVEMP include short latency inhibitory response and linearly increased response with increased intensity. Exploring the frequency tuning characteristics of mVEMP will delineate the resonant properties of mVEMP peripheral generators. Despite the fact that mVEMP shares vestibular afferents similar to cVEMP, there is no significant evidence to support the same. The literature supports using 500 Hz and 1000 Hz tone burst stimuli as optimal frequencies to elicit cervical and ocular VEMPs. The effect of different tone burst frequencies on mVEMP has not been explored yet. Hence, the study aimed to examine the effect of different tone burst frequencies on latency and amplitude of mVEMP in healthy adults.

Methods

Thirty-two participants, aged 18–28 years (18 males and 14 females), were recruited for the study. All the participants had bilateral normal hearing sensitivity and normal middle ear function with no associated vestibular symptoms and oromandibular disorders. Inventis Piano audiometer with calibrated MX-41/AR Headphones (telephonics) was used for pure-tone audiometry. Grason-Stadler Incorporated Tympstar (GSI VIASYS) Health Care was used for tympanometry and reflexometry. Neuro-Audio ABR system (Neurosoft Inc.) was used to record mVEMP. Written consent was taken from all the participants before commencing the tests. The study was approved by the ethical review board (AIISH Ethics Committee for Biobehavioral Research) of the All India Institute of Speech and Hearing, Mysore, Karnataka, India (ref.: no. DOR.9.1/Ph.D/PTV/918/2021–22 dated 02.02.23).

Procedure for recording mVEMP

mVEMP was recorded ipsilaterally for all the participants at 500 Hz, 750 Hz, 1000 Hz, 2000 Hz, and 4000 Hz frequencies at an intensity of 125-dB SPL.The stimuli were presented through etymotic insert earphone ER 3A insert earphones. mVEMP was recorded using 2–1-2 ms rise, plateau, and fall time for all the frequencies using

a Blackman window. As suggested by Thirusangu and Sinha [26], the zygomatic electrode montage was used for recording mVEMP. Active electrode was placed on the lower third of the masseter muscle, reference electrode was placed on the midpoint of the zygomatic arch and ground on the forehead. The electrode placement is shown in Fig. 1.

The recorded responses were averaged for 200 sweeps, amplified by 5000×, and filtered between 0.1 and 2000 Hz. The analysis time window was set to 64 ms with 20 ms for prestimulus. The participants were asked to contract masseter muscles by simple clenching on both sides. Real-time muscle monitoring feedback (inbuilt feature in Neuro-Audio ABR system (Neurosoft Inc.) was provided during the recording, with 30 to 50% of the maximum contraction as the desired level. All the frequencies were recorded in a random fashion, and participants were provided 2 min of rest after each recording. The recording of the mVEMP has been submitted as a supplementary material with this manuscript (ESM1.mpeg). The video of the mVEMP was recorded at the Department of Audiology, All India Institute of Speech and Hearing, Mansagangothri, Mysuru, India.

Data analysis

The p11-n21 peaks were identified and marked. The EMG rectified peak-to-peak amplitude of p11-n21 was measured for all the frequencies from 500 to 4000 Hz measured for all the participants**.** Descriptive statistics were conducted to determine the mean and standard deviation of latency and amplitude parameters of mVEMP for all frequencies. Shapiro–Wilk's test was carried out to check the normal distribution of the data. Further, the Wilcoxson signed-rank test was done to compare the mVEMP latency and amplitude between the right and left ear. Friedman test and Wilcoxson signed-rank tests were carried out to find the effect of different tone burst frequencies on p11-n21 rectified amplitude of mVEMP.

Results

Response rate of mVEMP at different frequencies

mVEMPs were present for all 64 (100%) of the ears at 500 Hz and 750 Hz, whereas it was present for 63 (98%) ears at 1000 Hz, 54 (84%) ears at 2000 Hz, and 42 (65%) of ears at 4000-Hz stimuli.

The mean and standard deviation of latency and amplitude parameters of mVEMP for all frequencies for right and left ears separately are shown in Table 1.

Shapiro–Wilk's test of normality revealed non-normal distribution ($p<0.05$) of the data. Wilcoxson signed-rank test revealed no significant difference for p11 latency between the two ears for 500 Hz ($Z=0.00$, $p=1.00$), 750 Hz ($Z=0.45$, $p=0.64$), 1000 Hz ($Z=0.17$. $p=0.86$), 2000 Hz ($Z=0.67$, $p=0.50$), and 4000 Hz ($Z=0.46$, $p=0.64$). Wilcoxson signed-rank test revealed no significant difference for n21 latency between the two ears for 500 Hz (Z=1.74, $p=0.08$), 750 Hz ($Z=1.11$, $p=0.26$), 1000 Hz ($Z=1.79$, $p=0.07$), 2000 Hz ($Z=0.30$, $p=0.76$), and 4000 Hz ($Z=1.54$, $p=0.12$).

Wilcoxson signed-rank test revealed no significant difference for p11-n21 amplitude between the two ears for 500 Hz ($Z=0.64$, $p=0.52$), for 750 Hz ($Z=1.16$, $p=0.24$), for 1000 Hz ($Z=1.46$, $p=0.14$), for 2000 Hz ($Z=0.70$, $p=0.48$), and for 4000 Hz ($Z=1.66$, $p=0.09$). Overall Wilcoxson signed rank revealed no significant ear difference for both p11 and n21 latency and p11-n21 amplitude between the right and the left ear for all the frequencies.

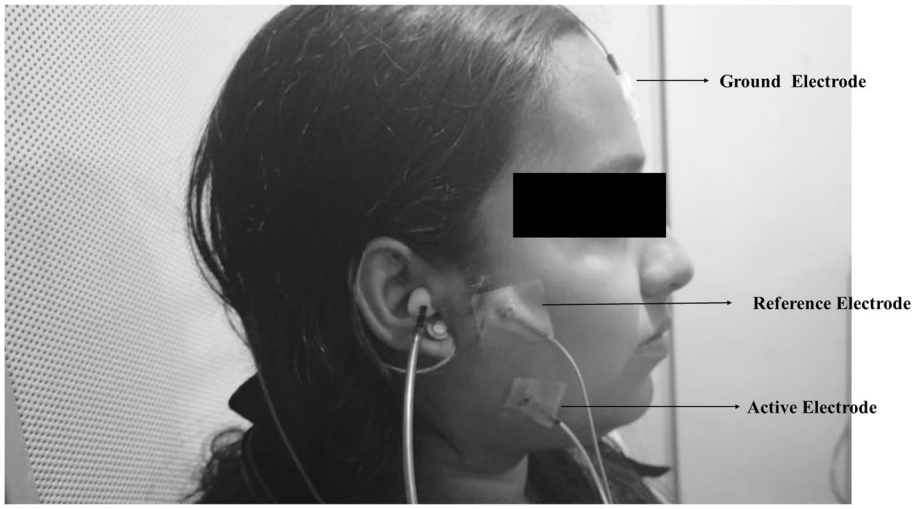

Fig. 1 The electrode montage used in the study

Table 1 Mean and standard deviation of p11 and n21 latency and p11-n21 amplitude for different tone burst frequencies

Frequency	p11 latency				n21 latency				p11-n21 amplitude			
	RE*		LE		RE		LE		RE		LE	
	M (ms)	SD (ms)	M (ms)	SD (ms)	M (ms)	SD (ms)	M (ms)	SD (ms)	M (μv)	SD (μv)	M (μv)	SD (μv)
500 Hz	13.96	1.39	14.09	1.70	21.26	1.34	21.70	1.60	0.81	0.34	0.85	0.36
750 Hz	14.0	1.31	14.1	1.46	21.85	1.39	22.08	1.64	0.84	0.32	0.91	0.36
1000 Hz	13.95	1.41	13.91	1.69	21.09	1.51	21.51	1.80	0.75	0.25	0.84	0.37
2000 Hz	14.28	1.50	14.19	1.46	21.16	1.89	21.60	1.56	0.68	0.20	0.72	0.20
4000 Hz	14.88	1.47	15.22	1.15	21.78	1.74	22.62	1.48	0.60	0.21	0.73	0.25

* *RE-*, right ear; *LE*, left ear; *M*, mean; *SD*, standard deviation; *μV*, microvolt; *ms*, millisecond

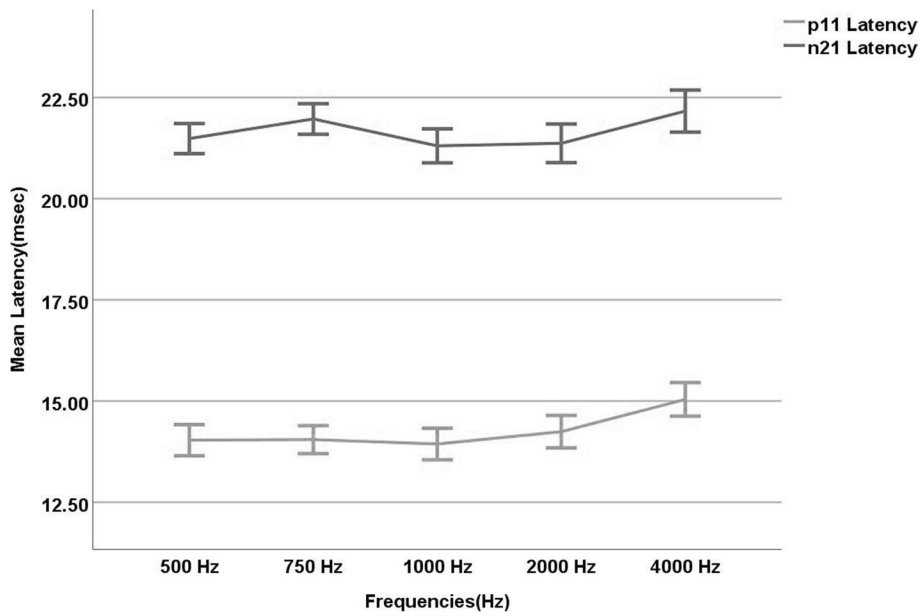

Fig. 2 Mean and standard deviation of p11 and n21 latency for combined data across frequencies

Hence, the right and left ear data was combined. Figure 2 shows the mean and the standard deviation of p11 and n21 latency of the combined data, and Fig. 3 shows the mean and the standard deviation of p11-n21 rectified amplitude of the combined data.

The individual and grand averaged waveforms of recorded mVEMP for all the frequencies of the combined data are shown in Fig. 4.

Friedman test revealed no significant main effect for p11 latency between different frequencies, χ^2 (4) = 9.44, $p = 0.05$. Hence, further statistical analysis was not performed for p11 latency. In contrast, the Friedman test revealed a significant main effect for n21 latency between different frequencies: χ^2 (4) = 16.96, $p = 0.002$. Further, the Friedman test also showed a significant main effect for the mVEMP amplitude between different frequencies χ^2 (4) = 34.18, $p = 0.00$. Since multiple comparisons had to be made, Wilcoxson signed-rank test with Bonferroni corrections was applied. After applying the Bonferroni correction, the significance level was adjusted to 0.005. Table 2 shows the Wilcoxson signed-rank test values for the n21 latency and p11-n21 rectified amplitude complex for the different frequencies pair.

The results of Table 2 indicate that the amplitude of the p11-n21 peak was not different between 500 and 750 Hz, 500 Hz and 1000 Hz, and 2000 Hz and 4000 Hz. There was a significant difference in the amplitude of the p11-n21 peak for all the other frequency pairs. Overall, the amplitude of the p11-n21 peak for 500 Hz and 750 Hz was higher than the other frequencies. p11 latency was not different at different tone burst frequencies; however, n21 latency was different between 750 and 1000 Hz.

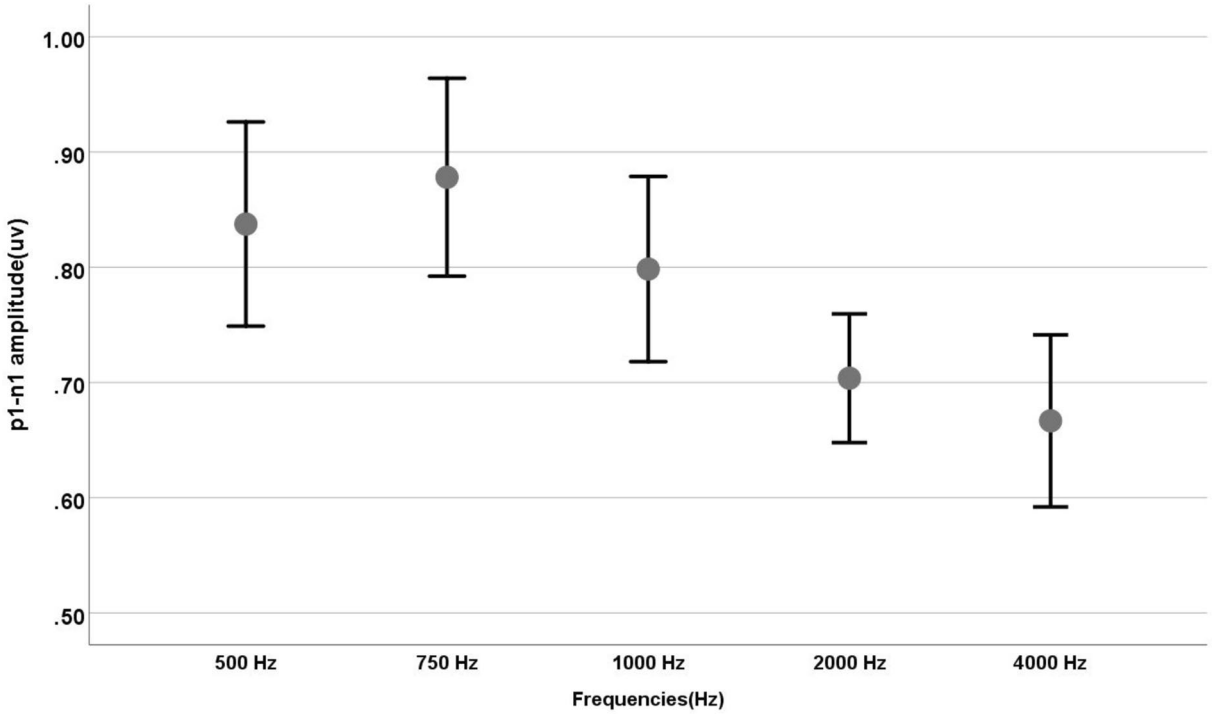

Fig. 3 Mean and standard deviation of p11-n21 amplitude for combined data across frequencies

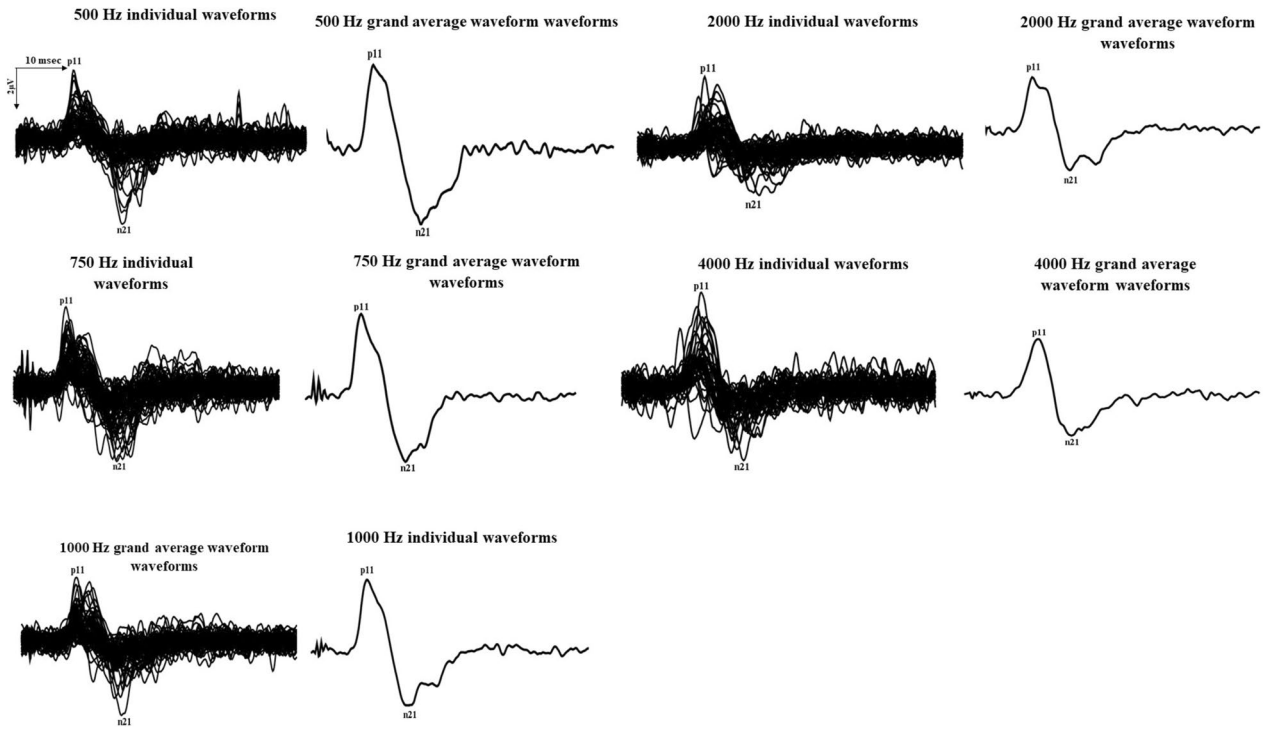

Fig. 4 The individual and grand averaged waveforms of recorded mVEMP for all the frequencies of the combined data

Table 2 Results of Wilcoxson signed-rank test for n21 latency and p11-n21 amplitude across the frequency pairs of mVEMP

Frequency pairs	n21 latency		p11-n21 amplitude	
	Z	*p*	Z	*p*
500 Hz vs 750 Hz	2.42	0.015	1.68	0.92
500 Hz vs 1000 Hz	0.67	0.49	1.82	0.069
500 Hz vs 2000 Hz	0.81	0.414	3.84	0.00*
500 Hz vs 4000 Hz	1.35	0.176	3.85	0.00*
750 Hz vs 1000 Hz	3.06	0.002*	3.18	0.001*
750 Hz vs 2000 Hz	2.42	0.015	4.64	0.000*
750 Hz vs 4000 Hz	0.37	0.708	4.02	0.000*
1000 Hz vs 2000 Hz	0.26	0.793	3.07	0.002*
1000 Hz vs 4000 Hz	2.25	0.024	3.34	0.001*
2000 Hz vs 4000 Hz	1.62	0.104	1.80	0.72

* Indicates ($p < 0.005$) significant difference observed between frequency pairs

Discussion

The study aimed to assess the effect of different tone burst frequencies on mVEMP ranging from 500 to 4000 Hz.

Response rate of mVEMP potentials

In the present study, the response rate of mVEMP for 500 Hz, 750 Hz,1000 Hz, 2000 Hz, and 4000 Hz was 100%, 100%, 98%, 84%, and 65%, respectively.

Park et al. [16] reported similar findings in cervical VEMPs with 100% of responses for 250 Hz, 500 Hz, and 1000 Hz, whereas 98% of response rate was reported for 2000 Hz. In oVEMPs, 500-Hz stimuli elicited a 100% response, whereas 250 Hz, 1000 Hz, and 2000 Hz elicited 80 to 95% response [16]. Govender et al. [15] recorded cervical VEMPs for tone burst frequencies ranging from 50 to 1200 Hz and reported a 90 to 100% of response rate for all frequencies. In the present study, we found 98 to 100% of the response rate until 1000 Hz in line with the literature. Singh and Barman [27] reported a 100% response rate of oVEMP at frequencies between 250 and 1000 Hz, 84% response rate at 1500 Hz, and 68% response rate at 2000 Hz. In cervical and ocular VEMPs, the higher prevalence rate was reported in response to 500-Hz tone burst, and the primary afferents were otoliths.

The mVEMPs were present in 100% of the subjects at 500 Hz and 750 Hz. Based on response rate, 500 Hz and 750 Hz would be the best frequencies to use to elicit the mVEMP.

Effect of tone burst frequencies in mVEMP p11-n21 latency and amplitude measures

The p11 latency of mVEMP across frequencies did not show a significant difference across frequencies; however, n21 latency revealed a significant difference between only 750 Hz vs 1000 Hz.

Govender et al. [15] studied cervical and ocular VEMPs of 250 Hz,500 Hz,1000 Hz, and 1500 Hz and reported p1 and n1 latencies decreased as the frequency increased from 250 to 1500 Hz. The mVEMP was not recorded at 250 and 1500 Hz stimuli in the present study. The latency of VEMP is largely affected by increase in overall stimulus duration. Cheng and Murofushi [28] studied the effect of stimulus duration on 500-Hz cVEMP and recommended a 1-ms rise/fall time as an optimal duration. In addition, increasing plateau time showed an increase in p11-n21 latencies and also an increase in p11-n21 amplitude [29]. Recent research recommended 2–5 ms duration of tone burst stimulus to elicit an optimal response for cVEMP and 2 ms for oVEMP [30]. The present study used constant 5-ms duration stimuli with 2-ms rise/fall time and 1-ms plateau across the frequencies. The constant duration of stimuli maintains the overall energy of stimulus constant across the frequencies. This could be the reason for no difference in latency of mVEMP peaks across the frequencies.

In the present study, the amplitude of mVEMP for both 500-Hz and 750-Hz stimulus was higher compared to the other frequencies. Park et al. [16] reported that 500 Hz and 1000 Hz were clinically effective as they elicited higher amplitude, lower threshold, and higher response rate in both cervical and ocular VEMPs. Takahashi et al. [17] also reported a better amplitude of cVEMP with 500 Hz and 750 Hz stimuli. Larger amplitude at 500 Hz or 750 Hz of VEMP could be due to the resonance properties of the otolith organs [29, 31]. Fu et al. [14] showed a linear decline in cervical and ocular VEMPs amplitude among 250 Hz, 500 Hz, 1000 Hz, and 1500 Hz as the frequency increases from 500 to 1500 Hz. A similar trend of amplitude decline was found in our study. The increased response rate and higher amplitude from 500 and 750 Hz in mVEMP support the vestibulo-trigeminal pathway's afferents, primarily the saccule and inferior vestibular nerve.

Todd et al. [32] studied frequency tuning of cervical VEMPs in healthy individuals and found highest response at frequency range of around 300–350 Hz. This could be due to mass-spring properties of otolith system modelled by second-order mechanical system. The greater mass of saccule with otoconia contributes to lower frequency. The inelastic membranous labyrinth contributes to stiffness properties. In combination, the mass and stiffness properties impede low- and high-frequency acoustic stimuli, respectively. However, at a particular frequency, both effect cancels where greater stimulation is expected naturally, called resonant frequency. Researchers equivocally support the frequency-tuning characteristics of

the vestibule in humans ranging around 500 to 1000 Hz based on cervical and ocular VEMPs [11, 15, 16]. The above study found 500 Hz/750 Hz tone burst stimuli as optimal tone burst frequency in eliciting the mVEMP responses.

Conclusions

To the best of our knowledge, tThis is the first study to evaluate the frequency-tuning characteristics of mVEMP in healthy adults. We found a 100% mVEMP response rate for 500 Hz and 750 Hz and 98% for 1000-Hz stimuli. Also, highest amplitude was found for 500 Hz and 750 Hz stimulus. The results of the present study are consistent with previous studies, where similar results were reported for cervical and ocular VEMPs. We recommend both 500 Hz and 570 Hz as optimal frequencies to elicit mVEMP. It would be interesting to see the frequency-tuning characteristics of mVEMP in various peripheral vestibular pathologies.

Abbreviations

mVEMP	Masseter vestibular-evoked myogenic potentials
cVEMP	Cervical vestibular-evoked myogenic potentials
oVEMP	Ocular vestibular-evoked myogenic potentials

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43163-023-00549-2.

Additional file 1: Supplementary Video file-ESM1.mpeg. The video file contains the video recording of the masseter VEMP.

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Authors' contributions

VPT was involved in designing the study, data collection, statistical analysis, and writing the report, and SKS were involved in design of the study, data analysis, interpretation of results, statistical analysis, and critical revision of the manuscript.

Funding

None to declare.

Availability of data and materials

The dataset generated or analyzed during the current study are not publicly available due to confidentiality as it is a part of PhD thesis but are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional research committee. The study was approved by the Ethical review board (AIISH ETHICS COMMITTEE FOR BIOBEHAVIOURAL RESEARCH) of the All India Institute of Speech and Hearing, Mysore, Karnataka, India (ref : No.DOR.9.1/Ph.D/PTV/918/2021-22 dated 02.02.23). Written consent was taken from all the participants before commencing the tests.

Consent for publication

Written informed consent was obtained from the participant for publication of accompanying images (Fig. 1).

Competing interests

The authors declare that they have no competing interests.

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