The Egyptian Journal of Otolaryngology

ORIGINAL ARTICLE Open Access

Optimum stimulus for eliciting masseter vestibular-evoked myogenic potential: a comparative exploration with three different acoustic stimuli

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Abstract

Objective To compare the EMG rectified amplitude, absolute latencies, interpeak interval, and Interaural asymmetry parameters of masseter vestibular-evoked myogenic potential (mVEMP) elicited using clicks, 500 Hz tone bursts, and 500 Hz NB CE-chirps.

Method Twenty-five young healthy adults in the age range of 18–27 years participated for the study. mVEMP was recorded using three different acoustic stimuli i.e., clicks, 500 Hz tone bursts, and 500 Hz NB CE-chirps. mVEMP was recorded at an intensity of 125 dB peSPL with 5.1/s repetition rate. The potentials were recorded ipsilaterally using zygomatic electrode montage and were filtered between 0.1 and 3000 Hz. EMG rectification of the responses was made prior to analysis.

Results The latencies of P1 and N1 were significantly earlier for chirps then followed by click and tone bursts. The EMG rectified amplitude was significantly larger for the potentials obtained using chirps followed by tone bursts and then the clicks. Masseter VEMP obtained using chirps had significantly larger interpeak interval than tone bursts and clicks. The mean amplitude asymmetry ratio was greater in the potentials obtained using chirps than the other two stimuli.

Conclusion The present study reveals that 500 Hz NB CE-chirps tend to produce mVEMP with larger response amplitude and earlier latencies and thus are considered better and constructive stimuli compared to clicks and tone bursts.

Keywords Masseter vestibular-evoked myogenic potentials (mVEMP), Vestibular-evoked myogenic potentials, Vestibular disorders, Tone burst stimulus, Chirp stimulus

Background

The vestibular-evoked myogenic potential (VEMP) measures the functional integrity of the vestibular reflex pathways arising from the utricle and the saccule. VEMP is considered a clinically promising neurophysiological test procedure to assess the functional integrity of the sacculo-collic and utriculo-ocular pathways in various vestibular disorders. VEMP can be recorded with galvanic stimulations [1], air conduction sounds [2], and bone conduction vibrations [3].

Originally, VEMP was recorded from the sternocleidomastoid (SCM) muscle, known as cervical VEMP [2, 4]. Later, another test method was adopted where the myogenic responses were recorded from the inferior oblique muscle, and this is known as the ocular VEMP [3, 5–7]. Since then, the cervical VEMP (cVEMP) and the

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ocular VEMP (oVEMP) have been the widely used tests employed to evaluate the integrity of the sacculo-collic and the utriculo-ocular pathways, respectively.

Recently, a new test known as the masseter VEMP (mVEMP) has gained more research and clinical interest in the field and is said to assess the vestibulo-trigeminal pathway [8]. In this, the myogenic responses are recorded using surface electrodes placed on tonically contracted masseter muscles, and the responses are recorded ipsilaterally/contralaterally/bilaterally. The masseteric reflex can be recorded from auditory and vestibular stimulations [9–12]. A preliminary study showed that the acoustic jaw reflex was present only in those with normal hearing and intact auditory nerves [9]. Hearing-impaired patients with intact vestibular systems did not manifest any jaw reflex to intense acoustic stimulations around 90–100 dB. Thus, the authors presumed that the acoustic-jaw reflex originates from the cochlear receptors, not the vestibular end organs. They also stated that it could be a sign of local protective or the startle reflex toward loud sounds [9].

A preliminary research study demonstrated two components of masseter VEMPs: one component was vestibular in origin, whereas the other one was cochlear in origin [8]. The recent research studies on mVEMP have employed acoustic stimuli such as clicks [11–15], tone bursts [16–20], and CE-chirps [21] to elicit the masseter VEMP responses. Vignesh et al. [16] compared the mVEMP responses obtained using tone bursts with that of those obtained with clicks in a study by de Natale et al. [22]. The authors concluded that the tone burst stimuli produced more robust p11/n21 peaks than click stimuli; the latencies of the peaks were more prolonged, and the amplitude was larger when tone burst was used to elicit mVEMP. The peak-to-peak amplitudes of the mean EMG were larger when tone bursts were used rather than clicks to elicit mVEMP. The only similarity reported in the mVEMP responses obtained using clicks and tone bursts was that the corrected amplitude asymmetry ratio of the ipsilateral and contralateral responses was indistinguishable [16].

Another study reported that the mVEMP latencies of p11-n21 are shorter when elicited using clicks and 500 Hz NB CE-chirps than compared to those obtained with 500 Hz tone bursts [21]. 500 Hz NB CE-chirps tend to have earlier presentation time compared to tone bursts, and this could be the reason for the presence of early latencies when chirps were procured [23–26]. Duration of tone burst stimulus is relatively longer than that of stimuli clicks and chirps; saccule and the vestibular nerves are hypothesized to respond effectively when stimulated using a long-duration stimulus [27–31]. This study aims to explore how different stimuli such as clicks, tone bursts, and chirps affect the different parameters of mVEMP, such as amplitude, latencies, asymmetry ratio, and interpeak interval of mVEMP. Optimizing the stimulus in a healthy population is very important as the information can be used to determine the optimum stimulus to incorporate among the clinical population.

Methods

Participants

Twenty-five young healthy subjects with no history or complaint of audio-vestibular-related issues participated in this study. The age of the participants ranged from 18 to 27 years ($\bar{x}=22.3$). None of the participants reported any vestibular signs, symptoms, and other medical issues. All the subjects had normal hearing. Case history also revealed the presence or absence of any middle ear disorders. The participants were informed about the entire procedure, and informed consent was obtained from all the participants.

Procedure

Pure tone audiometry was carried out for all the participants across the octave band frequencies ranging from 250 to 8000 Hz for air conduction and 250 to 4000 Hz for bone conduction. Both air conduction and bone conduction thresholds were obtained using the modified Hughson-Westlake procedure [32]. Tympanometry and reflexometry were carried out to ensure they had no middle ear pathologies. Acoustic reflexes were obtained for both ipsilateral and contralateral stimulations for 500 Hz, 1 kHz, 2 kHz, and 4 kHz stimuli.

Masseter VEMP recording

Masseter VEMP was recorded for the participants using three stimuli, i.e., 0.1 ms clicks, 500 Hz tone bursts, and 500 Hz NB CE-chirps. Masseter VEMP was recorded ipsilaterally for all the participants. The NeuroAudio hardware and the Neurosoft software were utilized to record the mVEMP responses. Zygomatic electrode montage was used for the placement of the surface electrodes, which is as follows: the active or non-inverting electrode was placed on the lower third of the masseter muscle, the reference electrode was positioned at the midpoint of the zygomatic arch, and the ground electrode was placed on the forehead. All three stimuli were delivered using calibrated ER-3A insert earphones. The participants were seated in a non-recliner chair and were instructed to clench their teeth at the time of the presentation of the stimuli. They were asked to maintain the muscle contraction at a level ranging between 30 and 50% of the maximum contraction. An EMG visual feedback was provided to the participants, with which an appropriate muscle contraction was established throughout the test

procedure. The stimuli were presented at 125 dB peSPL at a repetition rate of 5.1 per second. The epoch time was set to 70 ms with a pre-stimulus duration of 10 ms. A total of two hundred stimuli were presented during the recording. The obtained responses were averaged, amplified by 5000X, and filtered between 0.1 and 3000 Hz.

Data and statistical analysis

The latency and the EMG rectified peak-to-peak amplitude of the p11 and n21 peaks recorded with clicks, 500 Hz tone bursts, and NB CE-chirps were obtained. The statistical analysis was carried out using the Statistical Package of Social Science (SPSS Version 25). Descriptive statistics were carried out to calculate the mean and standard deviation of the latency and amplitude of the response data. The obtained data's normality was verified using the Shapiro–Wilk test of normality. A paired sample *t*-test was administered to check statistically significant differences in the latency and amplitude between the right and the left ears. This was carried out for all three stimuli conditions. Repeated measures ANOVA was used to measure the significant main effect for latency, amplitude, interaural amplitude asymmetry ratio and interpeak interval parameters of mVEMP evoked with different stimuli. Bonferroni post hoc test was carried out to determine the pairwise comparison of the latency parameters between the three stimuli conditions.

Results

The study aimed to compare the P1 and N1 latency and the P1-N1 amplitude of mVEMP recorded with three stimuli (click, tone burst, and chirp). The response rate of the mVEMP with three stimuli was 100%, i.e., mVEMP responses were present in all twenty-five healthy individuals for click, tone burst, and chirp stimuli. The individual and grand averaged waveform of mVEMP for all three stimuli are shown in Figs. 1 and 2.

The latency and amplitude of mVEMP for all the twenty-five normal young healthy populations are given in Table 1.

It can be seen from Table 1 that the latency is earlier for the chirp stimulus, followed by the click and tone burst stimulation. It can also be seen that the amplitude of mVEMP is more for the chirp stimulus followed by the tone bursts and click stimuli. The Shapiro–Wilk test showed a normal data distribution ($p > 0.05$). Paired sample *t*-test showed no significant differences between left and right ear for click-evoked P1 latency [$t(24) = 1.11$, $p = 0.27$], N1 latency [$t(24) = 1.60$, $p = 1.21$] and P1-N1 amplitude complex [$t(24) = 1.97$, $p = 0.60$]. The paired sample *t*-test showed no significant differences between the left and right ears for tone burst-evoked P1 latency [$t(24) = 0.37$, $p = 0.71$], N1 latency [$t(24) = 1.71$, $p = 0.11$], and P1-N1 amplitude complex [$t(24) = 0.40$, $p = 0.68$]. Paired sample *t*-test showed no significant differences between the left and right ears for chirp-evoked P1 latency [$t(24) = 1.45$, $p = 0.16$], N1 latency [$t(24) = 0.93$, $p = 0.35$], and P1-N1 amplitude complex [$t(24) = 1.39$, $p = 0.17$]. Hence, the data from the two ears were combined for further analysis. The latency and amplitude of the combined data are given in Figs. 3 and 4, respectively.

It can be seen from Figs. 3 and 4 that the latency of P1 and N1 peaks is early for chirp stimulus, whereas the amplitude of the P1-N1 complex is more for chirp stimulus. Repeated measures ANOVA showed a significant main effect for latency parameters of mVEMP-evoked with different stimuli [$F(5, 245) = 768.30$, $p = 0.00$]. The results for the Bonferroni pairwise comparison of the latency parameters between the three stimuli are given in Table 2.

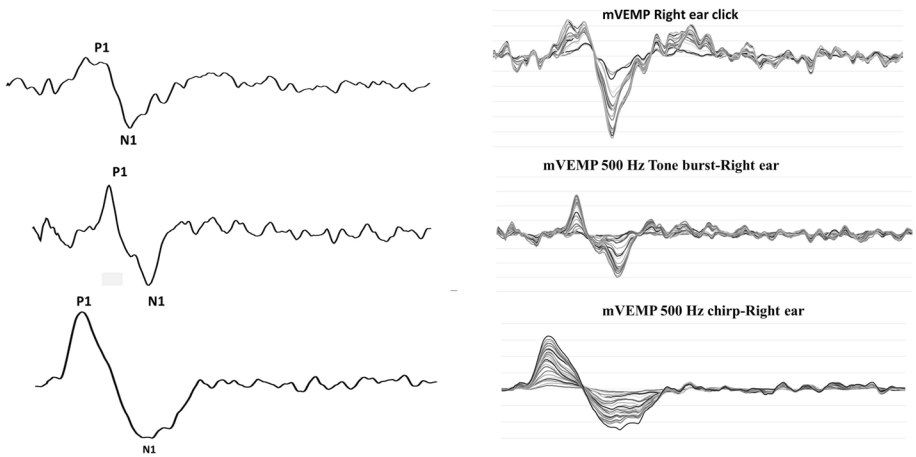

Fig. 1 Grand average and individual mVEMP recorded with a click, tone burst, and chirp stimulus for the right ear

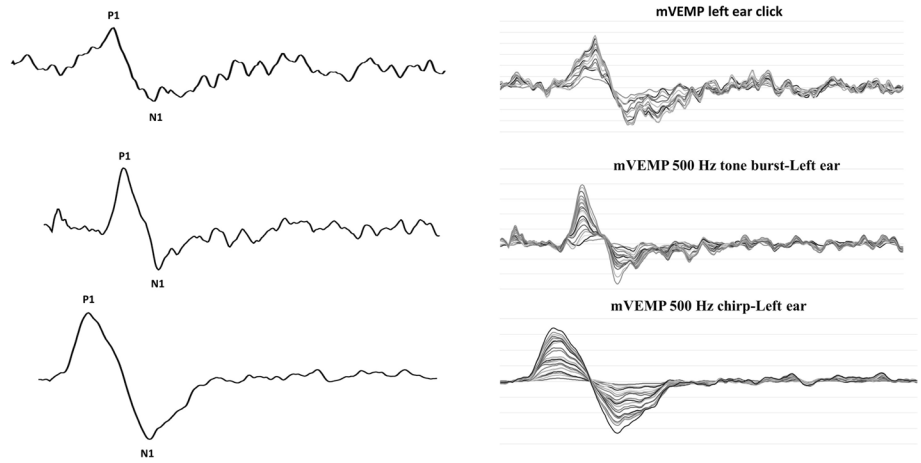

Fig. 2 Grand average and individual mVEMP recorded with a click, tone burst, and chirp stimulus for the left ear

Table 1 Latency and amplitude parameters of mVEMP for click, tone burst, and chirp

Stimulus	Parameters	Minimum	Maximum	Mean	Standard deviation
Click	P1 latency right	11.00	15.70	13.23	1.35
	P1 latency left	11.40	16.70	13.52	1.42
	N1 latency right	17.50	21.40	19.54	1.11
	N1 latency left	17.20	22.90	19.95	1.53
	P1-N1 amplitude right	0.20	0.90	0.44	0.25
	P1-N1 amplitude left	0.10	0.90	0.39	0.22
	Asymmetry ratio	0.00	33.33	16.62	11.71
Tone burst	P1 latency right	12.30	16.50	14.19	1.20
	P1 latency left	11.80	17.10	14.27	1.47
	N1 latency right	18.80	24.10	21.33	1.39
	N1 latency left	17.20	23.90	21.82	1.47
	P1-N1 amplitude right	0.30	1.60	0.83	0.31
	P1-N1 amplitude left	0.50	1.60	0.86	0.30
	Asymmetry ratio	0.00	33.33	13.99	9.94
Chirp	P1 latency right	6.10	10.70	7.78	1.19
	P1 latency left	5.70	10.70	8.19	1.39
	N1 latency right	14.00	21.00	21.00	1.71
	N1 latency left	15.10	21.30	18.22	1.32
	P1-N1 amplitude right	0.60	1.70	0.99	0.24
	P1-N1 amplitude left	0.60	2.00	1.09	0.37
	Asymmetry ratio	0.00	47.83	15.83	12.04

Repeated measures ANOVA also showed a significant main effect for the amplitude parameter of mVEMP evoked with different stimuli [$F(2, 98) = 67.24$, $p = 0.00$]. The results for the Bonferroni pairwise comparison for the amplitude parameters between the three stimuli are given in Table 3.

In addition, the interpeak interval between P1 and N1 peak latencies was calculated for three stimuli. The mean and the standard deviation for the interpeak interval for three stimuli are given in Fig. 5.

Repeated measure ANOVA also showed a significant main effect for the interpeak interval between the P1 and N1 peaks for three stimuli [$F(2, 98) = 109.48$, $p = 0.00$]. Bonferroni pairwise test revealed a significant difference between the interpeak interval of P1 and N1 peaks for three stimuli ($p > 0.05$).

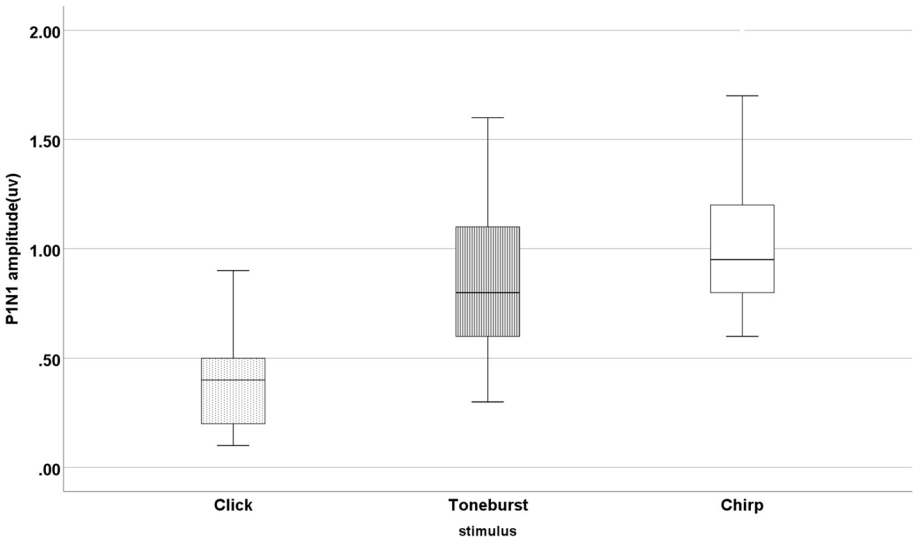

Fig. 3 P1-N1 amplitude of click, tone burst, and chirp stimulus of combined data

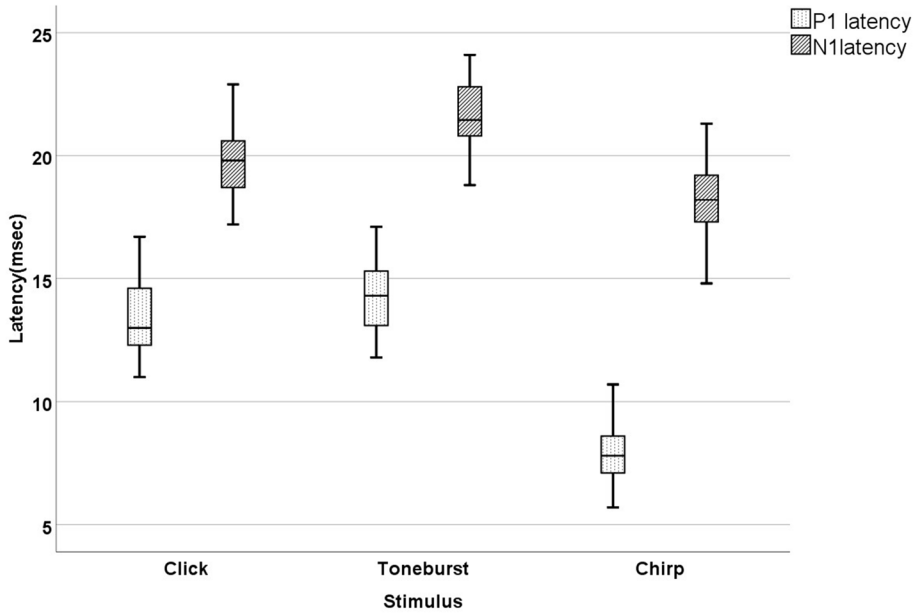

Fig. 4 Latency of P1 and N1 peaks of click, tone burst, and chirp stimulus of combined data

Table 2 Bonferroni pairwise comparison test results for comparison of latency parameters between different stimuli

	P1 latency chirp	P1 latency tone burst	N1 latency chirp	N1 latency tone burst
P1 latency click	$p < 0.05$	$p < 0.05$		
N1 latency click			$p < 0.05$	$p < 0.05$
P1 latency chirp		$p < 0.05$		
N1 latency chirp				$p < 0.05$

Table 3 Bonferroni pairwise comparison test results for comparison of amplitude parameters between different stimuli

	P1N1 chirp	P1N1 tone burst
P1N1 click	$p < 0.05$	$p < 0.05$
P1N1 chirp		$p < 0.05$

The mean amplitude asymmetry ratio was higher for clicks compared to the other two stimuli. However, the range of asymmetry ratio was higher for the chirp stimulus compared to the click and tone burst. Repeated measure ANOVA failed to show a significant main effect for the asymmetry ratio between the three stimuli [$F(2, 48) = 0.489$, $p > 0.05$].

To summarize the results, the latency of P1 and N1 peaks was significantly earlier for the chirp stimulus compared to the click and tone burst stimulus. The latency between click and tone burst was significantly earlier for the click stimulus than for the tone burst stimulus. The amplitude of the P1-N1 complex is significantly higher for the chirp stimulus than click and tone burst stimulus. The amplitude is greater for the tone burst stimulus between click and tone burst stimuli than the click stimulus. In addition, the interpeak interval between P1 and N1 peaks was significantly larger for the chirp stimulus than the tone burst and click stimulus. Between the click and tone burst, the interpeak interval was larger for the tone burst stimulus compared to the click stimulus.

Discussion

The present study aimed to compare the masseter VEMP responses obtained using three different acoustic stimuli i.e., clicks, 500 Hz tone bursts, and 500 Hz NB CE-chirps. Reliable masseter VEMP responses were obtained with good wave morphology and replicability from all the subjects using clicks, 500 Hz tone bursts, and 500 Hz NB CE-chirps. VEMPs are affected by various stimuli-related factors such as type of stimuli, level, and frequency [33]. It needs to be noted that the present study has employed commercially available NB CE-chirps that has been precisioned with respect to the time domain in order to compensate for the cochlear traveling wave delay [34, 35]. Elicitation of mVEMP responses is due to the frequency selectivity of 500 Hz NB CE-chirps, equivalent to the otoliths' resonant frequency [25].

The peak-to-peak amplitude and the absolute latencies of p11 and n21 using all three stimuli were measured and compared. The results revealed that 500 Hz NB CE-chirps elicited much earlier peaks than the other two stimuli. The shorter latency obtained on procuring 500 Hz NB CE-chirps is because of the stimuli construction design and the way it has been precisioned with respect to the time domain [35]. VEMPs are influenced by the rise time of the stimulus [36]; thus, clicks have elicited peaks with shorter latencies compared to 500 Hz tone bursts. The longer rise time and fall time of 500 Hz tone bursts is the main factor that leads to the elicitation of peaks with longer latencies and shorter amplitude than chirps [23].

Moreover, the onset and the offset of the 500 Hz NB CE-chirps arrive even before the onset of the clicks

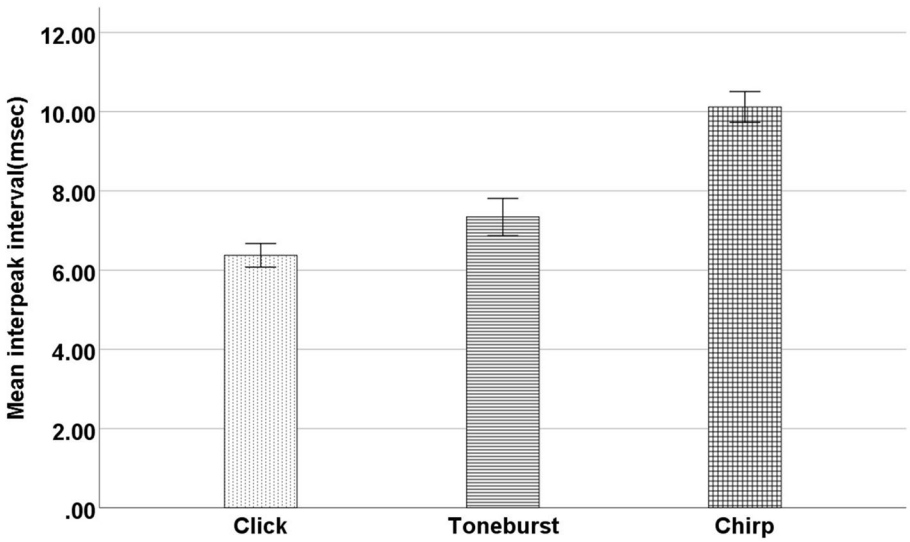

Fig. 5 The interpeak interval between P1 and N1 peak latencies for three stimuli

[34]. A similar study on cervical VEMP using the three stimuli revealed that chirps tend to produce higher response rates than the other two stimuli conditions. A study employed a custom-made chirp with an onset similar to clicks and tone bursts; their study findings revealed no difference in the latency of the cVEMP peaks obtained using all three stimuli conditions [37]. Band-limited chirps (containing frequencies from 250 to 1000 Hz) are found to produce latencies longer than clicks and tone bursts [38]. Thus, it could be concluded that the elicitation of earlier peaks in mVEMP is solely due to the construction design of the 500 Hz NB CE-chirps.

The amplitude of mVEMP was found to be larger for chirps followed by the tone burst and then the clicks. The larger amplitude of mVEMP evoked by chirp stimulus could be attributed to the fact that the chirps have a combined advantages of both clicks and tone bursts while eliciting VEMPs, i.e., the energy of 500 Hz NB CE-chirps are in resonance with the otoliths resonant frequency unlike clicks (clicks causes smearing of responses due to the presence of multi-frequencies). Moreover, unlike tone bursts, the NB CE-chirps stimulate a good set of nerve fibers in and around the stimulating frequency. Elicitation of larger amplitudes by NB CE-chirps is advantageous during the administration of masseter VEMP. Since mVEMP responses are smaller in amplitude than the cervical VEMPs, it is advisable to use NB CE-chirps to obtain larger amplitude responses.

No significant differences were noted in the amplitude and latencies between the right and left ears for the responses procured using all the stimuli conditions. This finding is in agreement with other studies on cervical, ocular, and masseter VEMPs obtained using chirp stimuli [21, 24, 38]. The current study also revealed the presence of an increased interpeak interval in the mVEMP responses recorded using 500 Hz NB CE-chirps compared to other stimuli conditions. This could be attributed to the rise-fall time of the stimuli. Chirps tend to have a comparatively shorter rise time than clicks and tone bursts. Rise time is said to have a crucial effect on the amplitude and the latency of the onset peaks of the VEMP [39, 40]. Thus, it is very well observed in our study that the 500 Hz NB CE-chirps with the shortest rise time have elicited P1 latency much earlier compared to the other two stimuli. The presence of early P1 has given rise to an increased interpeak interval on implementing 500 Hz NB CE-chirps. These findings of the interpeak intervals obtained using the three stimuli conditions are on par with another study, where they compared the cVEMP responses obtained using chirps, clicks, and tone burst stimuli. Moreover, VEMPs are usually sensitive to the variations in the stimuli acceleration with time [39].

Even though the mean asymmetry ratio obtained using clicks was higher, there was an evident increase in the range of asymmetry ratio elicited using 500 Hz NB CE-chirps. A similar finding was reported by another research study, where there was a larger inter-individual dispersion of the asymmetry ratio obtained between the two ears using 500 Hz NB CE-chirps to elicit ocular VEMP [25]. Moreover, they reported such dispersion with tone burst stimuli too. This finding was attributed to the variation that could happen due to the differences in the electrode montage. The greater the distance between the reference and the active electrodes, the better the amplitude with lesser Interaural asymmetry, as it would significantly diminish the reference contamination during the recording of the muscle potential [25]. This finding can also be comparable with the current study as the size of the muscle potential of mVEMP is similar to that of oVEMP. Moreover, the distance between the active and the reference electrodes is lesser in both mVEMP and oVEMP when compared to cVEMP. Thus, in the case of our study, the more extensive range of Interaural asymmetry could be due to the shorter interelectrode distance and smaller muscle potentials.

Summary and conclusions

The present study has inferred that the 500 Hz NB CE-chirps elicit peaks with shorter latencies and larger amplitudes and, thus, are said to be a better acoustic stimulus in eliciting mVEMP responses. As the amplitude of the peaks obtained using chirps is larger, fewer sweeps would be sufficient to elicit reliable mVEMP responses and distinguish the actual peaks from the baseline. This would be beneficial while testing subjects sensitive to louder sounds. Future studies can explore whether the trend of amplitude and latencies across the three stimuli conditions differ among the clinical populations, which would provide a deeper insight regarding the neural excitation patterns with respect to different stimuli in such individuals. Also, the test-retest reliability of the masseter VEMP should be checked in healthy and clinical population for all three (click, tone burst and chirp) stimuli.

Abbreviations

mVEMP	Masseter vestibular-evoked myogenic potentials
oVEMP	Ocular vestibular-evoked myogenic potentials
cVEMP	Cervical vestibular-evoked myogenic potentials
EMG	Electromyography
500 Hz NB CE-chirps	500 Hz narrow band Claus Elberling chirps

Acknowledgements

The authors thank the Director of AIISH, Mysuru, for granting permission to do the research paper. The authors also wish to thank HOD Audiology, AIISH, Mysuru, for permitting us to use the equipment for data collection. The author also thanks all the participants of the study for their voluntary participation.

Authors' contributions
AN was involved in the data analysis and manuscript writing; VPT was involved in the data collection, statistical analysis, and writing of the report; GM was involved in the data collection and statistical analysis; SKS was involved in the 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 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.SH/EC/SP-6/2023-24 dated 26.09.2023). The participants were informed about the entire procedure, and informed consent was obtained from all the participants.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 6 October 2023 Accepted: 22 December 2023
Published online: 23 January 2024

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